U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-287 128

Algae and Water Pollution

Mervin C. Palmer, Kennett Square, PA

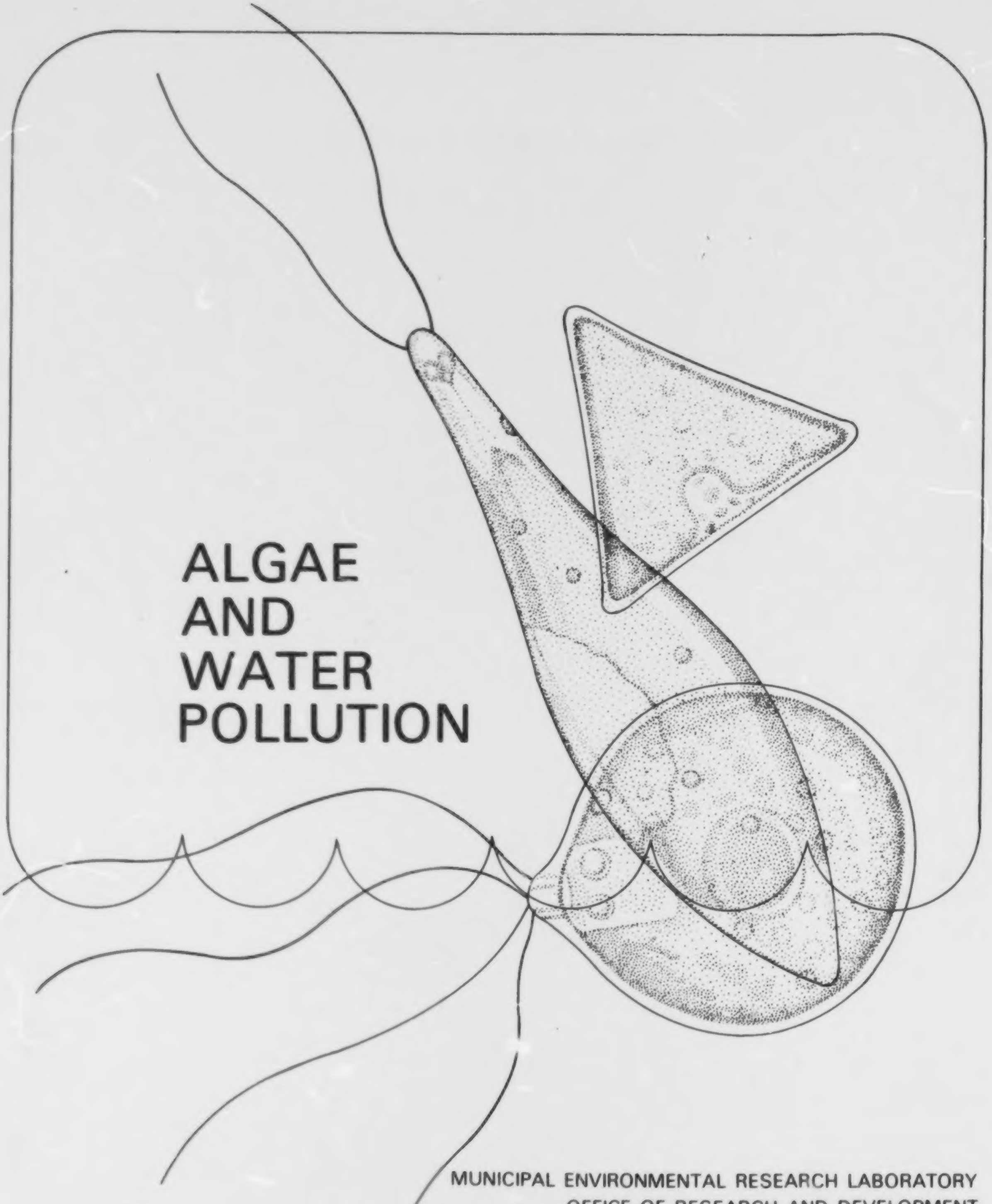
Prepared for

Municipal Environmental Research Lab, Cincinnati, OH

Dec 77

PB 287128

1



ALGAE AND WATER POLLUTION

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

133

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/9-77-036	2.	3. RECIPIENT'S ACCESSION NO. PB287128
4. TITLE AND SUBTITLE ALGAE AND WATER POLLUTION		5. REPORT DATE December 1977 (Issuing Date)
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) C. Mervin Palmer		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Kendal at Longwood, Box 220 Kennett Square, PA 19348		10. PROGRAM ELEMENT NO. 1BC611
		11. CONTRACT/GRANT NO. 68-03-0232
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory--Cin.,OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 1973-1976
		14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES
Revision and expansion of Dr. Palmer's manual Algae in Water Supplies

16. ABSTRACT

Algae are involved in water pollution in a number of important ways. It requires a continuous monitoring and study of algae existing in waters of various quality in order to determine what controls or what changes or what uses can be instituted for the benefit of man and for conservation of water and of desirable aquatic life.

This manual presents a simplified identification key limited to algal species of importance in water supplies and associated with pollution. The most important species are illustrated in three-dimensional drawings in color. The manual also deals with the ecology and significance of algae and presents information on filter clogging and mat forming algae, attached forms, algicides and algal control, algae associated with pollution (both fresh water and estuarine), various uses of algae, algae of rivers and lakes, eutrophication, algae as indicators of pollution, methods of recording algae, and the use of algae in waste stabilization lagoons for the treatment of domestic and/or industrial wastes.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Algae* Water pollution* Identification* Illustrations* Fresh water Estuaries	Systematic key Colored	13B 06C

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 133
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE PCA07

EPA Form 2220-1 (9-73)

☆U.S. GOVERNMENT PRINTING OFFICE: 1978-760-318

EPA-600/9-77-036
December 1977

ALGAE AND WATER POLLUTION

An Illustrated Manual on the Identification, Significance, and Control of Algae in Water Supplies and in Polluted Water

C. Mervin Palmer
Illustrations in color by Harold J. Walter
and Sharon Adams
Edited by Ronald L. Lewis

COLOR ILLUSTRATIONS REPRODUCED
IN BLACK AND WHITE

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

1-A

DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research, a most vital communication link between the researcher and the user community.

As part of these activities, this illustrated manual was prepared to aid those people concerned with water supply and pollution control, to prevent or control problems caused by undesired algal growth, and to help them create conditions suitable for beneficial use of algae for pollution control.

Francis T. Mayo, Director
Municipal Environmental Research Laboratory

PREFACE

A manual on this general subject entitled *Algae in Water Supplies* was published in 1959. Approximately fifty thousand copies have since been printed by the U.S. Government Printing Office, divided among eight printings. In 1962, the Agency of International Development of the U.S. Department of State arranged for the translation of the manual into Spanish and for its printing in Mexico from where it was distributed throughout Latin America. This Spanish edition included a special bibliography of technical papers in English, Spanish, French, German, Portuguese, and other languages dealing specifically with algae in Latin America. It was printed for distribution, in part, by Centro Regional de Ayuda Tecnica. Agencia para el Desarrollo International (AID), Mexico, and in part, by Editorial Interamericana. S.A.

In 1964, the late Dr. Kuwahara, who had previously spent some time at the Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio, translated *Algae in Water Supplies* into Japanese and had it printed serially in seven issues of the *Journal of Water and Waste* (Japan) beginning with Volume 6, Number 7. Color plates of the English language edition were included in black and white.

Color plates were also included in the twelfth through fourteenth editions of *Standard Methods for the Examination of Water and Wastewater* published by the American Public Health Association, American Water Works Association, and Water Pollution Control Federation.

The U.S. Environmental Protection Agency, National Environmental Research Center, Cincinnati, Ohio, in 1973 had enlarged posters of the six color plates printed for distribution.

This present manual is primarily an enlargement of the previous manual but with greater emphasis on algae associated with water pollution. New chapters include "Algae in Streams," "Algae and Eutrophication," "Algae and Pollution — Estuarine," "Algae as Indicators of Water Quality," and "Algae in Sewage Stabilization Ponds." Additional material has been added to all of the other chapters and many more algae have been included in the completely revised Key in the Appendix. The chapters and color plates have been rearranged.

Grateful acknowledgment for aid and encouragement is given particularly to Dr. Robert Bunch, Chief, Treatment Process Development Branch, Wastewater Research Division, Municipal Environmental Research Laboratory (Cincinnati, Ohio), U.S. Environmental Protection Agency. Persons responsible for negotiating the contract to revise the manual, and with responsibilities for seeing that it was carried out satisfactorily, are James W. Geiser, Contracting Officer, Dr. Ronald F. Lewis, Project Officer, and E. M. Hennessey, Contract Negotiator. Credit for producing the colored illustrations of algae goes to Sharon Adams for Plates V and VI and to Harold J. Walter for the others. All new photographs and line drawings were furnished by the writer. The writer expresses his indebtedness to these co-workers listed above and to others for their aid in preparation of the new manual.

C. Mervin Palmer
Aquatic Biologist (Retired)
Interference Organisms Studies

Present address:
Kendal at Longwood, Box 220
Kennett Square, Pennsylvania 19348

Ronald L. Lewis
Biological Treatment Section
Treatment Process Development Branch
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

CONTENTS

Foreword iii
Preface iv
I. Introduction 1
II. Significance of Algae 3
III. Identification of Algae 6
IV. Algae in Streams 18
V. Plankton Algae in Lakes and Reservoirs 22
VI. Attached Algae 26
VII. Algae and Eutrophication 31
VIII. Clean Water Algae 34
IX. Algae and Pollution—Fresh Water 36
X. Algae and Pollution—Estuarine 40
XI. Algae as Indicators of Water Quality 42
XII. Algae in Sewage Stabilization Ponds 46
XIII. Taste and Odor Algae 52
XIV. Filter and Screen Clogging Algae 57
XV. Additional Problems Caused by Algae 60
XVI. Additional Uses for Algae Found in Water Supplies 68
XVII. Procedures for Enumeration of Algae in Water 75
XVIII. Control of Algae 78

Appendix

Key to fresh water algae common in water supplies and in polluted waters 98
Bibliography 111
Glossary 119

TABLES

Number

1 Comparison of the Four Major Groups of Algae in Water Supplies 13
2 Algae in Water Supplies. A List of the More Important Species 13
3 Recent Changes in Names of Algae 17
4 Common Algae, Except Diatoms, of Streams 21
5 Plankton and Other Surface Water Algae 24
6 Attached Algae 29
7 Algae Affecting Operation of Canals 30
8 Predominant Algae in Oneida Lake, 1961 33
9 Phytoplankton in Lake Erie, 1951 - 1952 33
10 Clean Water Algae 35
11 Pollution Algae - Algae Common in Organically Enriched Areas 39
12 Algal Genus Pollution Index 45
13 Algal Genera in American Sewage Ponds 50
14 Algae Most Abundant and Widespread in Sewage Ponds 50
15 Various Conditions of Sewage Oxidation - Stabilization Ponds 51
16 Taste and Odor Algae, Representative Species 55
17 Odors, Tastes, and Tongue Sensations Associated with Algae in Water 56
18 Filter and Screen Clogging Algae 59
19 Additional Problems Caused by Algae in Water Supplies 66
20 Uptake of Cesium-137 by Algae 66
21 Maximum Concentration Factors for Isotopes in Columbia River Organisms 67
22 Relative Concentration of Radioactive Material in Various Types of Organisms 67
23 Other Uses for Algae in Water Supplies 72
24 Relative Toxicity of Copper Sulfate to Algae 81

ILLUSTRATIONS

Color plate

I Plankton Algae in Lakes and Reservoirs 82
II Attached Algae 84
III Clean Water Algae 86
IV Fresh Water Pollution Algae 88
V Estuarine Pollution Algae 90
VI Sewage Pond Algae 92
VII Taste and Odor Algae 94
VIII Filter and Screen Clogging Algae 96

Figure

1 Accumulation of algae floating on the surface of water 4
2 Water net, *Hydrodictyon reticulatum*. 7
3 *Spirogyra ellipsospora* 7
4 *Spirogyra varians* 7
5 A blue-green alga, *Desmonema wrangelii* 7
6 A green alga, *Pediastrum boryanum*. 7
7 A desmid, *Cylindrocystis brebissonii*. 7
8 *Anacystis cyanea* (formerly *Microcystis aeruginosa*) 7
9 *Agmenellum quadriduplicatum* (formerly *Merismopedia glauca*) 7
10 *Phytoconis botryoides* (formerly *Protococcus viridis*) 7
11 *Haematococcus lacustris* (formerly *Sphaerella lacustris*) 7
12 Colonies of indefinite form in *Oocystis novae-semliae* 9
13 A simple filament, *Anabaena constricta* 9
14 Threads are grouped into erect cones in *Symploca muralis* 9
15 Filament with alternate branching in *Microthamnion strictissimum* 9
16 A branching, tubular, nonseptate alga, *Botrydium granulatum* 9
17 Cells embedded in a gelatinous tube in *Hydrurus foetidus* 9
18 Mature and young portions of *Compsopogon coeruleus* 9
19 *Microcoleus paludosus*, showing a single thread and a group of threads surrounded by a sheath, under high and low magnification 12
20 *Scenedesmus quadricauda*, showing spine-like extensions on the terminal cells . 12
21 Lateral flagella in *Merotrichia capitata* 12
22 Anterior flagella on cells of *Pleodorina illinoisensis* 12
23 Posterior and lateral views of anterior flagella on *Gonium sociale* 12
24 Two spore-producing cells on filaments of *Trentepohlia aurea* 12
25 Enlarged terminal reproductive cells on filaments of *Audouinella violacea* 12
26 Terminal cells specialized for sexual reproduction in *Vaucheria arechavaletae* ... 12
27 Thick-walled zygospores formed during sexual reproduction in *Zygnema normani* 12
28 True branching in the blue-green alga, *Nostochopsis lobatus* 12
29 *Anacystis (Microcystis)* 20
30 *Anabaena* 20
31 *Oscillatoria* (two sizes) 20
32 *Oocystis* 20
33 *Actinastrum* 20
34 *Scenedesmus* (reproducing) 20
35 *Ankistrodesmus falcatus* 24
36 *Gloeotrichia natans* 24
37 Plankton diatoms, showing distinctive shapes of cells and colonies 24
38 *Vaucheria geminata* 27
39 *Vaucheria sessilis* 27
40 *Pithophora oedogonia* 27
41 *Schizomeris leibleinii* 27
42 *Stigonema hormoides* 27

43 *Tetraspora* ... 27
44 *Calothrix* ... 27
45 *Enteromorpha* ... 30
46 *Oedogonium* ... 30
47 *Stigeoclonium* (immature) ... 30
48 *Calothrix parietina* ... 35
49 *Ulothrix zonata* ... 37
50 *Oscillatoria limosa* ... 37
51 *Oscillatoria tenuis* ... 37
52 *Oscillatoria princeps* ... 37
53 *Phormidium uncinatum* ... 37
54 *Synedra* and *Nitzschia* ... 44
55 *Melosira* (indicator alga) ... 44
56 *Pandorina* (indicator alga) ... 44
57 *Euglena* (indicator alga) ... 44
58 *Kirchneriella subsolitaria*, the alga used in the Vermont test ... 44
59 *Achnanthes*, a sewage pond diatom ... 48
60 Some flagellate algae producing tastes and odors ... 54
61 Pulses, over a four year period, of three taste and odor algae in a water supply reservoir ... 54
62 *Closterium lunula* ... 61
63 *Lyngbya majuscula* ... 62
64 *Nodularia spumigena* ... 63
65 *Scenedesmus bijugatus* ... 70
66 *Trachelomonas hispida* ... 71
67 *Scenedesmus obliquus* ... 71
68 *Pediastrum duplex* ... 71
69 *Chlorogonium euchlorum* ... 71
70 Nannoplankton counting slide ... 76
71 Typical form of algal plankton record ... 76
72a Experimental testing of a potential algicide: Applying the algicide to a blanket of algae ... 79
72b Experimental testing of a potential algicide: Result of the test: Blanket of algae has disappeared ... 79

CHAPTER I

INTRODUCTION

Since the quality of water affects our lives in many ways, water must be of good quality if its aesthetic value in the scenic environment is to be appreciated. Polluted water can be the reason for the closing of both commercial and sport fishing areas and restricting the recreational use of bodies of water. Water quality can have a great influence on the ability of aquatic plants and animals to exist and grow in a stream, lake, pond, or bay. Water used to manufacture many industrial products must be of good quality to prevent a reduction in the quality and value of the manufactured product. Water of poor quality costs more to be treated for use as a community water supply. Poor water can affect our health since it can carry disease agents and toxic chemicals and it may have an unpalatable taste or a disagreeable odor. The temperature, clarity, and color of the water can affect the quality of the water.

As population and industrial demands increase and groundwater supplies become inadequate, more and more cities and villages are turning to lakes, streams, or reservoirs for their water supplies. This change from ground to surface source of supply has created many new problems for those engaged in the procurement and treatment of water for domestic and other uses. Groundwaters are essentially free of organisms which may complicate the provision of potable water. Some problems are odor and taste, the clogging of filters, growths in pipes as well as in cooling towers and on reservoir walls, surface water mats or blooms, infestations in finished waters, and toxicity.

Pollution of surface water has become one of the more important problems about which to be concerned. It requires consideration and action by individuals, civic groups, city, state, and national sanitary and health departments, and by industry.

Algae are involved in water pollution in a number of significant ways. Pollution may bring about an enrichment of the algal nutrients in water and this may selectively stimulate the growth of a few types, producing massive surface growths or "blooms" that in turn reduce the water quality and affect its use. Certain algae are able to flourish in water polluted with organic wastes and to play an important part in "self-purification" of the body of water. The selective types of algae that exist in polluted water also are being used as indicators of pollution. Polluted water algae may frequently include certain forms toxic to man or animals drinking the water or living in it. Since algae constitute part of a chain of aquatic life in the water, whatever alters the number and kinds of algae affects all of the other organisms, including fish. Thus it requires a continuous monitoring and study of algae existing in waters of various quality in order to determine what controls, what changes, or what uses can be instituted for the benefit of man and for conservation of water and desirible aquatic life.

The number and kinds of algae and other organisms which grow in surface waters depend on environmental conditions. Fertilizing materials such as sewage and organic wastes from milk plants, canneries, slaughter houses, paper mills, starch factories, and fish processing plants greatly increase the productivity of the waters and their crops of algae and other plankton organisms, many of which produce problems when they become abundant.

In muddy streams such as the Missouri, turbidity limits light penetration sufficiently so that few problems occur from algal growth. When impoundments are built in such a stream, they create settling basins in which the water clears and algal growths develop, producing tastes and odors or other nuisance conditions. The extensive impoundment program which has been underway for 40 years can create many water supply problems which did not exist previously in these waters.

Pool size, shape, depth, amount of shore line, extent of shoal areas, character of the bottom, physiography and soils of the watershed, amount and rate of precipitation, sunlight, and the quality of the water are all factors influencing the growth of algae in a reservoir. A narrow, deep reservoir having no shoal areas, a minimum of shore line, little wind mixing, an unproductive watershed, and soft water low in dissolved solids will have less algae than a wide, shallow, irregular reservoir located in an area of rich soil where the incoming water is rich in dissolved materials and there is complete wind mixing. In many areas the best reservoir sites have already been utilized. New reservoirs will have to be built in less favorable sites where productivity of algae will be greater. In the Great Plains area and in several other parts of the country, reservoir sites for water storage are usually wide and shallow and favorable for the development of plankton growths.

In view of these conditions, problems caused by nuisance organisms will become more widespread and of greater importance. In several areas they are now the number one problem of water works operators. Attempts to control nuisance algae with chemicals has a long history.

Studies have been made to improve methods of using existing algicides and to find better or more specific materials. Specific algicides would be of considerable economic benefit, as smaller amounts of material could be used to control only undesirable forms without affecting the others. This is very important from the standpoint of fisheries management, as algae constitute much of the base of the food pyramid on which all the higher forms of aquatic life depend. Furthermore such a procedure provides a form of biological control. The application of very toxic materials in large dosages which will kill practically all the algae is undesirable. When much of the population is destroyed, the weed species come back first, and since there is little competition, in great abundance. If selective algicides can be discovered, their use will control the problem species, while the desirable forms can increase so that the undesirable species are less likely to come back in large numbers.

Algicidal and/or biological controls are feasible in lakes, small streams, or reservoirs where most of the water is used. They are economically unsuited to large lakes or rivers where only a portion of the water is used by the water plant. In such situations some other method of treatment must be provided in the water plant. It is believed that materials causing odor or taste are present in very small amounts. If the taste and odor materials produced by so-called nuisance organisms are known, it may be possible to treat or change them by additives to render them innocuous. Investigations have been conducted to recover, isolate, and identify odoriferous materials produced by algae and other organisms in water supplies.

Studies of attempts to control algal problems in water works, sewage ponds, and polluted waters have revealed hit-or-miss procedures, little coordination of effort, and only occasional systematic recording of essential data. The great majority of water and wastewater treatment plants are not staffed for making studies to determine the cause of their trouble, to identify the organisms responsible, or to detect their development. The value of continued surveillance of algal populations has been proven by studies in several of the larger water plants, sewage ponds, lakes, and streams. There has been a need for some time for a planned and uniform approach to these problems and for placing information in an understandable and useful form into the hands of those who need it. This manual is an attempt to meet this need in appraisal of algae in relation to water pollution problems and to furnish information for remedying some difficulties.

It is realized that very few operators or members of treatment plant staffs have had training in aquatic biology or in the identification of algae. However, if growths of algae are to be detected and controlled, stimulated, or left undisturbed, continued surveillance of plankton populations and identification of the organisms are essential. This manual presents a simplified identification key limited to species of importance in water supplies and associated with pollution. Terms and structures used in this key are defined and illustrated. The most important species of algae are illustrated in three-dimensional drawings in color which show both external and internal structures. The drawings are based on actual specimens and on descriptions from a large number of texts. It is believed that with these drawings and the key any person who applies himself diligently will be able to identify at least the most important forms. As experience is gained it should be possible to detect the development of troublesome algae so that control measures can be initiated before real trouble develops. In addition to the key and plates, the manual deals with the ecology and significance of algae and presents concise and pertinent information on filter-clogging and mat-forming algae, attached forms, algicides, and algal control, algae associated with pollution (both fresh water and estuarine), various uses of algae, algae of rivers and lakes, eutrophication, algae as indicators of pollution, methods of recording algae, and the use of algae in waste stabilization lagoons for the treatment of domestic and/or industrial wastes.

CHAPTER II

SIGNIFICANCE OF ALGAE

Algae are common and normal inhabitants of surface waters and are encountered in every water supply that is exposed to sunlight. While a few of the algae are found in soil and on surfaces exposed to air, the great majority of them are truly aquatic and grow in the waters of ponds, lakes, reservoirs, streams, and oceans. Operators of water treatment plants are aware of the ability of algae to produce odors and tastes and to clog sand filters. In addition, algae are recognized as important in water supply in many other ways, including their capacity for modifying the pH, alkalinity, color, turbidity, and in relation to the radioactivity of the water. Some types are undoubtedly the most troublesome of the various nuisance organisms, but others can actually be put to good use in improving a water supply.

One of the principal reasons for the importance of algae is their ability to give rise to very large quantities of organic matter in the water. It has been estimated, for example, that more than 130 tons of algae/day flow into Fox River, Wisconsin, from Lake Winnebago (1). Plankton algae in the Scioto River, Ohio, has reached a maximum of more than 8,000 ppm (2). Algal counts for Lake Michigan water at Chicago nave at times reached over 4,000 organisms/ml (3), and the White River in Indiana has records of counts exceeding 100,000 algae/ml (4). Such large quantities of algal material can always be counted on to cause serious difficulties in water treatment plants.

Small numbers of particular kinds of algae may also be troublesome. The diatoms *Tabellaria, Synedra,* and *Melosira* almost invariably reduce the length of filter runs. The brown flagellate, *Synura,* even in small numbers, is a notorious taste and odor producer. Comparatively low concentrations of most of the algae, however, are often an asset rather than a liability in raw waters.

Unattached, visible, and sometimes extensive accumulations of algae at or near the surface of the water are designated as blooms, mats, or blankets (fig. 1), the last two terms generally being applied when the algae are in the form of threads or filaments. Many of the algae attached to submerged rock, wood, soil, the surface of trickling filters, filter beds, or coagulation basin walls may form continuous carpets of growth. When the water becomes turbulent, fragments of the algal carpet may be detached and subsequently carried away. These massive growths of algae can be troublesome in clogging screens, in the production of slime, and as a source of tastes and odors particularly if anaerobic decomposition occurs. The blooms and surface mats can be the cause for complaints by persons using the body of water for recreational purposes. They may also be one cause of fish kills by acting as a barrier to the penetration of oxygen into water under the algae. Algae that are dispersed and not in blooms or mats normally would have just the opposite effect.

The algae that collect and grow on the surface of a slow sand filter as a gelatinous slimy film may be responsible for gradually reducing the flow through the bed, but they also perform a useful service by adding oxygen to the water, which permits the bacterial decomposition of organic matter within the filter to remain aerobic. Anaerobic activities in the sand bed would tend to render the filtrate less palatable. The slimy mass of algae and other aquatic plants and animals at the surface of a slow sand filter is called the filter skin and has also been referred to under the German name of *Schmutzdecke*.

Unattached microorganisms that are dispersed individually or in colonies in water are designated collectively as plankton. Included are the plankton algae, which constitute most of the phytoplankton (meaning plant plankton), and the planktonic animals or zooplankton. When the water supply comes from a large, deep reservoir or lake, the planktonic algae are likely to be of much more significance than the attached or benthic algae. Many water treatment plants, therefore, keep records of the plankton but not of the benthos. In some treatment plants it has been a general practice to apply an algicide to the raw water whenever the concentration of planktonic algae approaches a count of 500 areal standard units/ml (5).

All surface waters contain dissolved and suspended materials. Some of these serve as nutrients and support the growth not only of algae but of many other kinds of aquatic life, the numbers of which are governed to a great extent by the amounts and kinds of nutrients available. Some of the aquatic plants and animals are large, the fish, turtles, cattails, and water lilies, for example, but there are also immense populations of small forms, many of them microscopic. The microscopic organisms in addition to algae include bacteria, actinomycetes, minute worms, and mites. More recently, sub-microscopic viruses have been found to be common in water, and some of them prey on algae (6). Many of these aquatic organisms may play a major part in affecting the quality of the water and have to be dealt with in the process of preparing water for domestic and industrial use. The present account deals primarily with the algae, but it is obvious that the activities of one group of organisms are closely associated with those of other organisms present in the same environment.

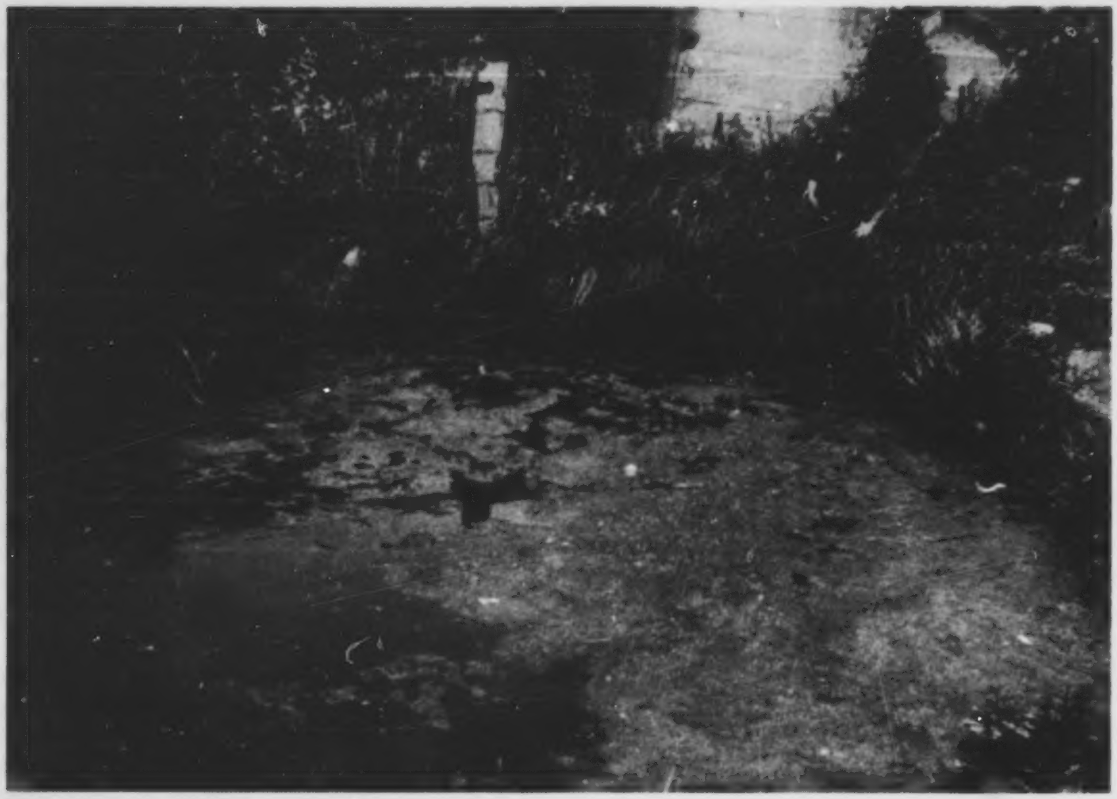


Figure 1.—Accumulation of algae floating on the surface of water.

PHOTOSYNTHESIS

Algae differ from the other groups of small or microscopic organisms in possessing an internal green pigment called chlorophyll, sometimes hidden or partially masked by other pigments, which enables them in the presence of sunlight to combine water and carbon dioxide to form starch or related substances, and to release oxygen into the water. This process, known as photosynthesis (7), is absent in all typical bacteria, actinomycetes, fungi, yeasts, protozoa, and crustacea. In general it is not characteristic of animals but is common to all types of green plants. Respiration, on the other hand, is a process carried on by all plants and animals and the gaseous exchange is the opposite of that in photosynthesis, i.e., oxygen is absorbed and carbon dioxide is released. However, in algae and other green plants the rate of photosynthesis is normally faster than that of respiration. These organisms, therefore, release more oxygen than they use and absorb more carbon dioxide than they release, while animals and other non-photosynthetic organisms release carbon dioxide and absorb oxygen from their environment. For this reason, the amount of oxygen and carbon dioxide in an environment such as water often depends to a large degree upon the relative rates of photosynthesis and respiration being carried on collectively by the algae, bacteria, and other organisms in that area.

Some aquatic pigmented forms containing chlorophyll are able to swim or crawl, although most of the typical algae are not capable of self locomotion. Many of these pigmented swimming forms have whip-like structures called flagella and have been classified by some workers as protozoan animals rather than as algae. However, it seems best in this document to classify them as algae (8).

The algae make possible important chemical changes and metabolic activities in the water through their release of oxygen during daylight hours. The oxygen is made available for respiration that is carried on by all types of animals from fish to the smallest forms. Oxygen helps to prevent foul or septic conditions by favoring the activities of aerobic rather than anaerobic bacteria. The algae constitute the primary source for continuous daytime renewal of this essential element in most bodies of quiet water. Oxygen release by algae and oxygen uptake by reaeration are the two primary sources for renewal of oxygen in flowing streams and turbulent water.

Another important chemical effect of algae is the continuous removal of carbon dioxide from the water during the daylight hours as a result of photosynthesis. This process brings about an alteration in the relative amounts of soluble (unbound) carbonic acid, intermediately soluble (half bound) bicarbonates, and the nearly insoluble (bound) monocarbonates, often causing some of the latter to precipitate. All of this produces a change in the total hardness of the water. Vigorous growths of algae have been known to reduce the water hardness by as much as one-third.

These changes in carbon dioxide and hardness also tend to change the pH of the water. The pH rises as the algae increase their photosynthetic activity during daylight hours. The pH then decreases at night when the algae are not carrying on photosynthesis but are releasing carbon dioxide in respiration. These changes in hardness and in pH must be taken into account at the water treatment plant, since they may require changes in the dosages of chlorine, alum, and other chemicals used in treatment.

Corrosive activity of the water is also often increased as a result of algal growth. This can have far-reaching effects on the pipes in the distribution system and on many industrial processes where water is in contact with the machinery. In California, algae attached to the metal walls of sedimentation tanks caused deep pits to be formed in the metal as a result of the depolarizing action of the oxygen produced by the algae. Algae in contact with submerged concrete blocks have caused complete disintegration of the concrete (9).

The substance produced by algae in photosynthesis is primarily a carbohydrate which may either be used in respiration or in construction of cell substances or stored, generally as starch or in some cases as an oil. Since aquatic organisms lacking chlorophyll are unable to manufacture carbohydrates or oils from inorganic matter, they are dependent upon algae and other green plants, directly or indirectly, for their source of these organic substances. Algae represent an essential and basic part of the cycle of living organisms. Live algae serve as food, especially for small aquatic animals, which in turn serve as food for larger forms. The remains of dead algae are utilized by bacteria and other scavengers.

Increasing attention is now being paid to algae that produce toxic organic substances causing the death of many kinds of wild and domestic animals. There are records of algae that are toxic to humans, and some have several times been looked upon with suspicion as the possible cause of certain outbreaks of gastro-intestinal disorders among persons using a common water supply.

Algae problems which relate to providing suitable water supplies, together with the use of some algae in water supply and sewage treatment improvements, clearly indicate a need for more knowledge of the environmental requirements of these organisms, their life cycles, growth, and nutrition.

Reports have been published for various parts of the continent which summarize the importance of algae and other interference organisms in water supplies and to water quality. The regions that have been covered include New England (10), the Chesapeake area (11), Indiana (12), Ohio (13), Pennsylvania (14), Virginia (15), West Virginia (16), Canada (17), California (18), and the South Central United States (19).

REFERENCES

1. Current pollution investigations and problems in Wisconsin. K. M. Mackenthun. In Biological Problems in Water Pollution, ed. by C. M. Tarzwell. Dept. Health, Education, and Welfare, Public Health Service, Robert A. Taft San. Eng. Center, p. 179-183. 1957.
2. A study of pollution and natural purification of the Scioto River. R. W. Kehr, W. C. Purdy, J. B. Lackey, O. R. Placak, and W. E. Burns. U.S. Public Health Service, Public Health Bull. 276, 153 p. 1941.
3. Quantitative study of the phytoplankton of Lake Michigan at Evanston, Illinois. K. E. Damann. Butler Univ. Bot. Stud. 5:27-44. 1941.
4. Plankton populations in Indiana's White River. J. B. Lackey and E. R. Hupp. Jour. Amer. Water Wks. Assn. 48:1024-1036. 1956.
5. Comprehensive survey of taste and odor problems. H. N. Lendall. Water Wks. Eng. 99:1237-1238. 1946.
6. Virus diseases in blue-green algae. R. S. Safferman. Chapter 21 in Man and the Environment, D. F. Jackson (ed.), Syracuse Univ. Press, Syracuse, N.Y., p. 429-439. 1968.
7. Photosynthesis in the algae. R. W. Krauss. Indust. and Eng. Chem. 48:1449-1455. 1956.
8. Suggested classification of algae and protozoa in sanitary science. C. M. Palmer and W. M. Ingram. Sewage and Indust. Wastes 27:1183-1188. 1955.
9. Biological corrosion of concrete. E. T. Oborn and E. C. Higginson. Joint Rept. Field Crops Res. Branch, Agric. Res. Service, U.S. Dept. Agric., and Bur. Reclamation, U.S. Dept. Interior. 8 p. Jan. 1954.
10. Algae and other interference organisms in New England water supplies. C. M. Palmer. Jour. New England Water Wks. Assn. 72:27-46. 1958.
11. Algae and other organisms in waters of the Chesapeake area. C. M. Palmer. Jour. Amer. Water Wks. Assn. 50:938-950. 1958.
12. Algae and other interference organisms in Indiana water supplies. C. M. Palmer and H. W. Poston. Jour. Amer. Water Wks. Assn. 48:1335-1346. 1956.
13. Algae in water supplies of Ohio. C. M. Palmer. Ohio Jour. Sci. 62:225-244. 1962.
14. Algae in relation to water quality in Pennsylvania. C. M. Palmer. Proc. Pa. Acad. Sci. 41:73-85. 1967.
15. Biological aspects of water supply and treatment in Virginia with particular reference to algae. C. M. Palmer. Va. Jour. Sci. 18 (New Series No. 1):6-12. 1967.
16. Algae and associated organisms in West Virginia waters: problems and control measures. C. M. Palmer. Castanea 32:123-133. 1967.
17. Survey of water purification practice in Canada. D. H. Matheson and A. V. Forde. Jour. Amer. Water Wks. Assn. 49:1522-1530. 1957.
18. Algae and other interference organisms in water supplies of California. C. M. Palmer. Jour. Amer. Water Wks. Assn. 53:1297-1312. 1961.
19. Algae and other interference organisms in waters of the South Central United States. C. M. Palmer. Jour. Amer. Water Wks. Assn. 52:897-914. 1960.

CHAPTER III

IDENTIFICATION OF ALGAE

Several of the large groups of algae are recognized by their common names, such as the diatoms, desmids, armored flagellates, euglenoids, greens, blue-greens, yellow-greens, browns, golden-browns, and reds. Included in these groups are numerous individual kinds which probably total more than twenty thousand. A few of the less specific kinds of algae have common as well as scientific names, for example, "water net" for *Hydrodictyon* (fig. 2), "green felt" for *Vaucheria,* "sea lettuce" for *Ulva,* "water silk" for *Spirogyra,* and "stone wort" for *Chara.* Each one of these is known as a genus (plural, genera) and is composed of specific kinds known as species (plural also is species). Two species of the genus *Spirogyra,* for example, would be *Spirogyra ellipsospora* (fig. 3) and *Spirogyra varians* (fig. 4). For the great majority of algae, however, only scientific names are available, no common names having as yet been applied to them.

Experience in water and sewage treatment plants has demonstrated that there is considerable difficulty in recognizing the various algae and in determining which of the many present are really important. In this manual the algae are considered and displayed according to their significance to sanitary scientists and technicians, rather than with regard to their evolutionary relationship as botanists would normally classify them (1). Obviously only a fraction of the total number of algae can be included, but many of those omitted are comparatively rare types or relatively unimportant in water supplies.

For convenience, most of the algae of importance in water supplies and water pollution may be categorized into four general groups, the *blue-green algae,* the *green algae,* the *diatoms,* and the *pigmented flagellates.* This is a simplification of the grouping which is used in more extensive treatises on the classification of algae. As might be expected, there are a few miscellaneous forms which do not fit into these four groups, brown, red, and yellow-green algae, for example. Desmids are a subgroup of the green algae. The blue-green algae include such forms as *Oscillatoria* (pls. IV and VIII), *Anacystis (Microcystis)* (pls. VII and VIII), and *Desmonema* (fig. 5). As the name implies, many of the specimens have a blue-green color. They are surrounded by a slimy coating. Their form and internal structure are comparatively simple. The green algae are exemplified by *Chlorella* (pls. IV and VIII), *Pediastrum* (fig. 6), and *Spirogyra* (pls. IV and VIII). Their most common color is grass-green to yellow-green, and the pigment is localized in plastids. Reserve food is generally starch. The desmids (fig. 7) are a subgroup of the green algae. The diatoms are represented by the genera *Cyclotella* (pls. III and VIII) and *Navicula* (pls. III and VIII). They have a rigid wall containing silica which is sculptured with regularly arranged markings. Their plastids are brown to greenish in color. Within the category of pigmented flagellates are placed all of the swimming algae which have flagella. *Euglena* (pls. I and IV) and *Synura* (pl. VII) and representatives of this group. A comparison of the more significant characteristics of the four groups of algae is summarized in Table 1.

A total of almost 500 genera and species of the most important algae is included in the next 11 chapters of this manual, being considered according to their occurrence and significance under the general titles of algae in streams, algae in ponds, lakes and reservoirs, attached algae, algae and eutrophication, clean water algae, algae and pollution—fresh water, algae and pollution—estuarine, algae as indicators of water quality, algae in sewage stabilization ponds, taste and odor algae, and filter and screen clogging algae. In Table 2, these algae are listed alphabetically, together with their group, the title under which they are discussed, and the plate or figure where they are illustrated. A key for identification of the fresh water forms is included in the Appendix. A number of additional algae are referred to briefly in Chapters XV and XVI but are not included in the key. More extensive manuals on both marine and freshwater algae would be required for their identification (2-8, 10-13).

Authorities have changed the names of several of the better known algae. The list of these changes which involve any algae referred to in the manual is given in Table 3. Most of the changes involve genera and species of blue-green algae and were reported by Drouet and Daily in 1956 (4). For example, *Microcystis* (fig. 8) is changed to *Anacystis, Coelosphaerium* is included under *Gomphosphaeria,* and *Merismopedia* (fig. 9) becomes *Agmenellum.* The name of the green alga *Protococcus* (fig. 10) is changed to *Phytoconis* (9). The pigmented flagellate *Sphaerella* (fig. 11) is now recognized as *Haematococcus* (2). More recently, changes have been suggested for names of filamentous blue-green algae, but these are not followed in this manual (14, 15).

Eight plates of illustrations in color together with photographs, line drawings, the key, and descriptions are included for use as aids in the identification of the significant forms. Six of the color plates of important algae are the work of artist-biologist Harold J. Walter, and were done under supervision of the author (16, 17). The original six paintings are on display at the U. S. Environmental Research Center in Cincinnati, Ohio. Plates V and VI were

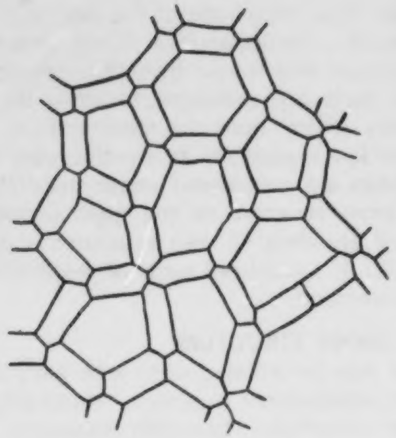


Figure 2.—Water net, *Hydrodictyon reticulatum.*

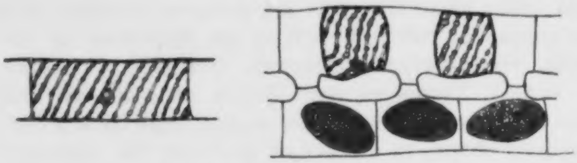


Figure 3.—*Spirogyra ellipsospora.*

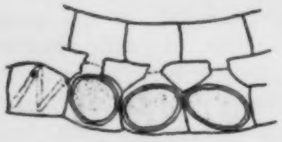


Figure 4.—*Spirogyra varians.*

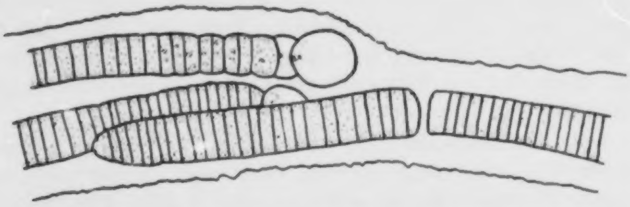


Figure 5.—A blue-green alga, *Desmonema wrangelii.*

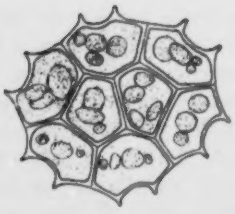


Figure 6.—A green alga, *Pediastrum boryanum.*

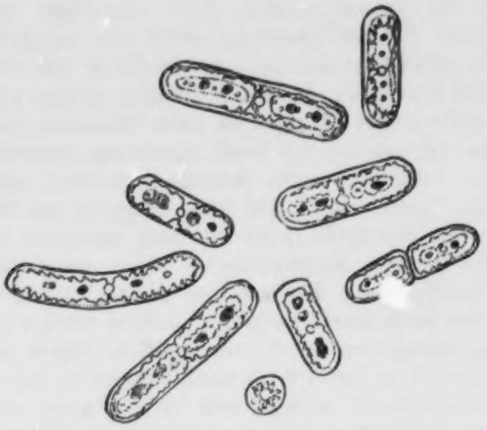


Figure 7.—A desmid, *Cylindrocystis brebissonii.*

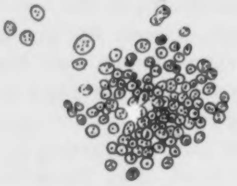


Figure 8.—*Anacystis cyanea* (formerly *Microcystis aeruginosa*).

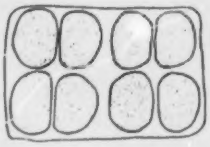


Figure 9.—*Agmenellum quadriduplicatum* (formerly *Merismopedia glauca*).

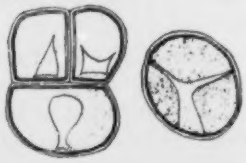


Figure 10.—*Phytoconis botryoides* (formerly *Protococcus viridis*).

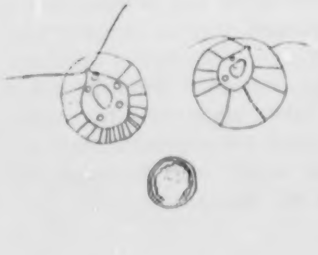


Figure 11.—*Haematococcus lacustris* (formerly *Sphaerella lacustris*).

painted by Sharon Adams from drawings made by the author. The line drawings which are included as figures throughout the manual were made by the writer and published previously in two taxonomic papers (18, 19).

The eight plates of algae in color represent four general areas of concern for plant operators; namely, water pollution, water treatment, sewage treatment, and water reservoirs. Taste, odor, and filter clogging are the most troublesome problems faced by many operators in water treatment plants. Representative algae associated with these conditions are illustrated on plates VII and VIII. In connection with water pollution, natural stream purification, and sewage treatment, the significant algae are those whose growth or survival is closely related to the amount and composition of sewage and other organic wastes in the water. Plates III and IV illustrate the contrasting freshwater groups of clean water and polluted water algae. In the reservoirs and settling basins of water supply systems are encountered the drifting, swimming, and attached growths of algae which can become troublesome in the raw water and can cause nuisance conditions in the treatment plant. Plates I and II illustrate respectively the planktonic and mat-forming algae of surface waters and the algae attached to the sides of reservoirs and settling basins. Algae in water of high organic content are illustrated in plates IV, V, and VI, the fourth and fifth contrasting the algae associated with pollution of fresh and estuarine waters.

The algae as illustrated on the plates are not shown in actual or relative size. Some of the forms illustrated are so minute as to be visible only under very high magnification of a compound microscope. Other forms are large enough to be seen under lower magnification or even with the unaided eye. *Chlorella* on plates IV and VIII, and *Chrysococcus* on plate III, are good examples of minute, microscopic algae while *Lemanea* on plate III, and *Chara* on plate II, are large forms often growing to a length of several inches. Thus, rather than having the same drawing scale for all of the algae, each is enlarged sufficiently to make clear its own particular characteristics. The magnification for each drawing is given with the species name in the list accompanying each plate.

The eight color plates contain illustrations of 174 of the algae referred to in this manual. Drawings and photomicrographs of some other forms are also included in the manual as noted earlier. The paintings and the drawings were prepared in such a way as to emphasize the characteristics most helpful in the identification of unstained material in water samples.

While illustrations may be a real aid in recognizing the various kinds of algae, an identification key is essential for distinguishing the many genera and species encountered. An original key, limited to the algae selected as most important in water supplies, has therefore been prepared for this manual. Since many other algae may be associated with these forms in the water, the supplementary use of additional treatises on algae would help to assure the greater accuracy in identifying the specimens.

When acquainted with the nature of an identification key, an observer can make direct use of the device in determining the name of a particular form whose essential characteristics have been determined through study under a microscope. It is necessary, therefore, to know the essential characteristics which must be observed in any specimen before the key is used for its identification. The essential characteristics are considered under the following headings: 1, gross structure of the alga, including shape, size, and cell grouping; 2, cell structure; 3, specialized parts of cells; 4, specialized parts of multicellular algae; and 5, measurements.

GROSS STRUCTURE

The cells of algae may be isolated units with each unicell behaving as an independent organism. Hundreds of genera of algae are unicellular. Examples illustrated include *Tetraedron, Euglena,* and *Gomphonema* on plate IV. In many other algae the cells are grouped together into various shapes of colonies such as are illustrated by *Asterionella, Hydrodictyon, Anacystis (Microcystis), Dinobryon, Volvox, Pandorina* and *Synura* on plate VII and *Oocystis* in figure 12. The colony of cells may have a definite, distinct shape, as in *Volvox,* or it may be indefinite and irregular, as in *Anacystis.* Colonies in the form of threads (filaments) where the cells are arranged in a simple linear series or chain are distinctive and very common (fig. 13). The threads may be isolated, or obviously grouped together as in *Symploca* (fig. 14); they may be unbranched (simple) or branched. The branches may be attached to the primary thread singly (alternate), in pairs (opposite), or in groups of more than two (whorled). *Anabaena, Spirogyra, Oscillatoria,* and *Arthrospira,* on plate IV are simple filaments. *Microthamnion* (fig. 15) and *Audouinella* (pl. II) have alternate branching; *Stigeoclonium* (pl. II) has, in part, opposite branching; and *Chara* (pl. II) has whorled branching. *Chaetophora* and *Phormidium* on plate II have filaments grouped together into larger growths.

In a few cases the alga may be in the form of a continuous, sometimes branching tube with no cell walls to divide the material into distinct units or cells. The tube is described as being nonseptate (having no transverse walls). *Botrydium* (fig. 16) and *Vaucheria* on plate II have this type of structure. In others such as *Hydryrus* (fig. 17) and *Tetraspora* on plate II, the whole gelatinous mass in which numerous cells are embedded is tubular in form.

A few freshwater algae have cells forming dense, massive strands, the strands being from a few to many cells thick and with central and marginal (peripheral) cells which differ from one another. *Lemanea* on plate III and *Compsopogon* on plate II and in figure 18 are examples of specialized strands. Finally, a limited number of algae have cells arranged to form a flat or bent membrane, as indicated by *Hildenbrandia* on plate III.

In summary, the gross structural forms encountered among the algae include the unicell, colony, filament, tube, strand, and membrane.

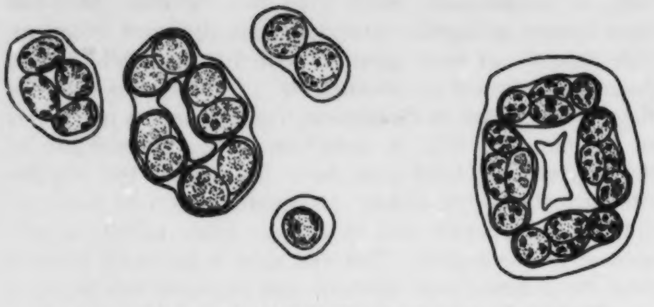


Figure 12.—Colonies of indefinite form in *Oocystis novae-semliae.*

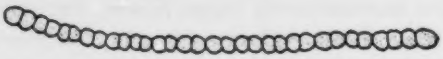


Figure 13.—A simple filament, *Anabaena constricta.*

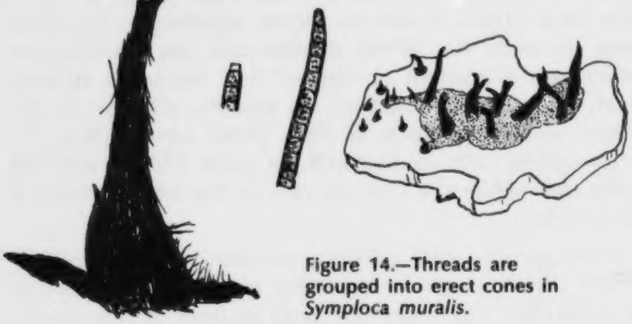


Figure 14.—Threads are grouped into erect cones in *Symploca muralis.*

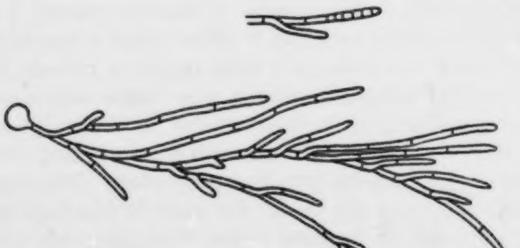


Figure 15.—Filament with alternate branching in *Microthamnion strictissimum.*

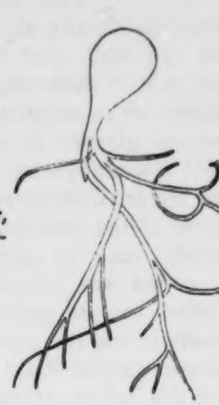


Figure 16.—A branching, tubular, nonseptate alga, *Botrydium granulatum.*

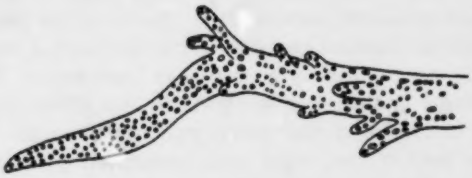


Figure 17.—Cells embedded in a gelatinous tube in *Hydrurus foetidus.*

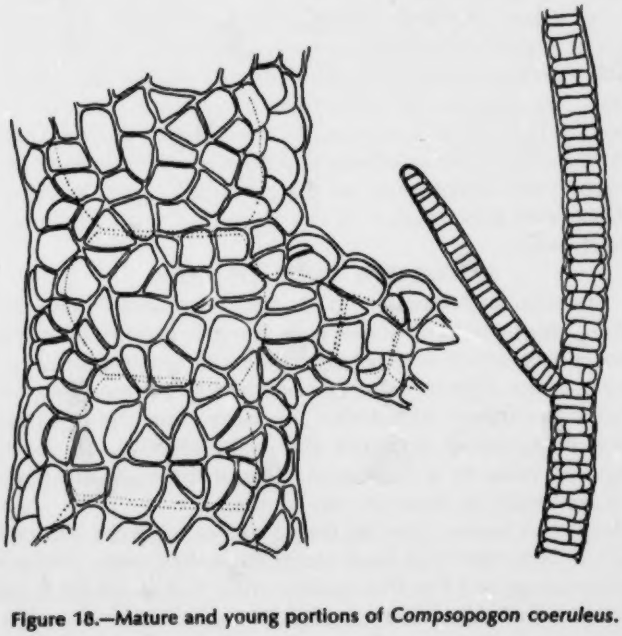


Figure 18.—Mature and young portions of *Compsopogon coeruleus.*

CELL STRUCTURE

The three main parts of many algal cells are the protoplast, the cell wall, and the outer matrix. Within the protoplast, one or more separate bodies of green, yellow-green, brown, or some other color may be present. These are known as plastids or chromatophores. In the blue-green algae (Myxophyceae) the pigments are not localized in plastids but are distributed throughout the whole protoplast. Some of the protoplasts may contain bodies other than plastids, such as nuclei, crystals, starch grains, oil droplets, called sap vacuoles, and spherical pyrenoids around which minute grains of starch collect. Pyrenoids are generally inside the plastids, as shown in *Chlorella* on plate VIII and *Oocystis* and *Scenedesmus* on plate I. The nucleus of the cell is present in all but the blue-green algae but seldom referred to in the manual, because it is colorless and difficult to observe without staining or other special treatment of the material.

The walls of algal cells are commonly a thin, rigid membrane which is in contact with the outer edge of the protoplast and completely surrounds it. Some of the swimming algae, such as *Euglena* on plate I, do not have a rigid wall and their protoplasts are therefore somewhat flexible, making them changeable in form. In the green algae the cell wall is semirigid and composed of cellulose. In diatoms the wall is very rigid and composed principally of silica that is sculptured with a regular, even pattern of lines and dots as illustrated by *Diatoma* and *Nevicula* on plate VIII.

The outer matrix, when present, tends in most cases to be flexible, colorless, gelatinous material which has been secreted through the cell wall. It often changes with age to become pigmented, to show stratification, and to develop a semirigid surface membrane. In most cases it assumes a form and structure characteristic for the particular alga of which it is a part. In *Botryococcus* (pl. I) its brown color partially hides the green plastids within the protoplasts. In *Gonium* (pl. I) it forms a sphere. *Dinobryon* and *Trachelomonas* on plate VIII have a specialized outer matrix called a lorica which is rigid and of definite form. *Lyngbya* and *Tolypothrix* on plate II and *Microcoleus* (fig. 19) have an outer matrix in the form of a semirigid tube-like sheath.

SPECIALIZED PARTS OF CELLS

Certain additional cell parts may be charcteristics useful in identification. Some cells have a gelatinous stalk, one end of which is attached to the cell and the other to some other object. *Gomphonema* and *Achnanthes* on plate II are shown with stalks. In many cases the cell may become detached from the stalk very readily. *Gomphonema* on plate IV is illustrated without the stalk, although it is generally present in this genus.

Knobs or spines may be found extending from the cell wall, or the cells may have sharp spine-like ends. *Micractinium* on plate I has true spines while *Ankistrodesmus* on plate III and *Scenedesmus* (fig. 20) have spine-like tips. Knob-like swellings on the cell wall are shown on the large cell of *Chlorococcum* on plate IV.

Swimming (motile) cells are often supplied with one, two, or occasionally more than two flexible, whip-like hairs known as flagella, extending from the front (anterior), side (lateral), or back (posterior) of the algal cell. Lateral flagella are found in *Merotrichia* (fig. 21) while anterior flagella are shown in *Pleodorina* (fig. 22), and in two views of *Gonium* (fig. 23). A reduction in the illumination of the microscope field may help in making the flagella (singular, flagellum) visible. Swimming cells may also contain a single, small, red or orange body called an eye spot in the protoplast. This eye spot is generally located near the anterior end. *Carteria* and six other motile algae are illustrated on plate IV.

Several special terms are required in the description of a diatom cell. The wall (frustule) of the diatom is composed of two approximately equal halves, the one, like a cover (epitheca), fitting with its edge over the edge of the other (hypotheca). When the cell is lying in the microscope field so that these overlapping edges are visible, the diatom is said to be presenting its girdle view. If the cell is lying so that the top of the epitheca or bottom of the hypotheca is visible, the diatom is said to be presenting a valve view. In *Gomphonema* on plate II the left hand cell is in girdle view and the right hand cell is in valve view. These views are shown together in *Gomphonema* on plate IV. When diatom cells are fastened together into a filament or ribbon, it is the valve surfaces which are attached together, so that the diatoms in the colony are always seen in their girdle view. Thus, the two attached cells in *Diatoma* on plate VIII present the girdle view while the isolated cell to the left is shown in valve view.

In diatoms the wall markings and partial partitions, particularly those visible in the valve view, are important in identification. The many fine lines or lines of dots (punctae) extending from the edge of the valve toward the center are known as striae, or when thicker, as costae. There may also be a longitudinal line called a raphe or true raphe extending from one end of the cell to the other but broken in the middle. If there is merely a clear space with no striae crossing it rather than a longitudinal line, the space is known as a false raphe or pseudoraphe. Motile diatoms generally have a true raphe which is apparently associated with their ability to swim or crawl. Partial wall-like partitions are called septa and extend lengthwise or crosswise into the protoplast. They appear as coarser lines than the striae. On plate III *Navicula* shows striae composed of punctae while *Pinnularia* has costae. Both diatoms have a true raphe. In *Diatoma* and *Synedra* on plate VIII a pseudoraphe is present. The former also has transverse septa. Longitudinal septa are seen in the girdle view of *Tabellaria* on plate VIII.

There are two major groups of diatoms, those circular in valve view, with radiating striae, and those elongate in valve view, with striae that tend to be transverse. The former are known as centric diatoms, and the latter as the pennate diatoms. On plate VIII *Cyclotella* and *Melosira* are centric in form while *Navicula* and *Cymbella* are of the pennate type.

SPECIALIZED PARTS OF MULTICELLULAR ALGAE

The shape of the end of a filament is an important diagnostic characteristic. The end cells may be essentially the same as other cells of the filament, or there may either be a gradual or an abrupt decrease in width (attenuation) to a point or even to a long spine or hair. On plate II, *Cladaphora* and *Lyngbya* have terminal cells essentially like others in the filaments while *Stigeoclonium* shows gradual and *Bulbochaete*, abrupt attenuation. Some of the filaments of blue-green algae have terminal cells which are swollen (capitate) or covered with a thick, cap-like or conical membrane (calyptra). These are present in *Oscillatoria* on plate III and *Phormidium* on plate II.

Some multicellular blue-green algae also have occasional special cells associated with the normal ones. One type, the heterocyst, generally is swollen, has a clear, colorless protoplast, and a thick wall with a knob-like thickening on the inside at the place or places where the cell is connected to the adjacent cell or cells. Heterocysts are shown in *Anabaena* and *Aphanizomenon* on plate VII. Another specialized cell, the resting spore (akinete), is swollen, has a dense, granular protoplast and a thick wall. It is illustrated in *Anabaena* on plate VII and *Cylindrospermum* and *Nodularia* on plate I.

A number of other specialized cells may be encountered in some of the algae, but these are too varied or too infrequently found to be dealt with here in detail. Many are reproductive cells (figs. 24-27). In some forms the sexual reproductive cells must be present before identification of particular species can be made. These structures are well described in other references (1,2).

A peculiar type of branching of filaments found in certain blue-green algae requires explanation. It is called false branching and is formed when a thread of cells splits crosswise. One or both segments break through the surrounding sheath at this point and a portion moves out to the side of the original thread, thus giving the appearance of branching. False branching is evident in *Tolypothrix* on plate II, while normal or true branching is shown in *Audouinella* and *Chaetorphora* on plate II, and a blue-green alga in *Nostochopsis* (fig. 28).

MEASUREMENTS

In some instances it is necessary to know the diameter or the length and width of the algal body (thallus) or of the individual cells before species belonging to the same genus can be distinguished. The unit of measurement is the micron, designated by the Greek letter μ. It is one one-thousandth of a millimeter or approximately one twenty-five thousandth of an inch. A linear scale on a glass disc (ocular micrometer) which can be placed on the interior shelf (diaphragm) of a microscope eye piece (ocular) can be calibrated in microns with the aid of a stage micrometer. The ocular micrometer can then be used to obtain measurements of algae. A Whipple micrometer, used in plankton counting, can also be calibrated in microns and thus serves in a similar manner.

TYPICAL DESCRIPTIONS OF ALGAE

A few examples of descriptions of algae adequate for their identification are given below as an indication of the information which would need to be obtained by microscopic observation before attempting to determine the genus and species name of the specimen.

Example No. 1: See *Chlorella* on plate VIII. Unicellular or in loose irregular colonies; cell spherical; no outer matrix; no projections or markings on the wall; protoplast with one cup-shaped, green plastid, filling most of the cell; one prominent pyrenoid in side or base of plastid; no great variation in size of cells; diameter of cells 3-5 microns.

Example No. 2: See *Phormidium* on plate II. Short cylindrical cells in simple filaments which are aggregated to form a mat, with formless gelatinous matrix between them; ends of filaments rather abruptly attenuate, bent, capitate, and with a conical calyptra; protoplasts homogeneous, blue-green throughout, no plastids; no heterocysts or akinetes.

Example No. 3: See *Fragilaria* on plate I. Numerous cells united side by side into a ribbon; contact of adjacent cells is continuous from one end of cell to the other; cells with fine transverse striations in the wall but absent in a wide band across the center; pseudoraphe present, septa absent; valve view narrowly elliptical but with sides parallel much of the way; end capitate; girdle view rectangular; protoplast with two brown linear plastids, one on each side; cell length, 25-100 microns.

Example No. 4: See *Chrysococcus* on plate III. Unicellular; protoplast with two brown lateral plastids and anterior red eye spot; protoplast surrounded by a brown spherical lorica with internal swelling at posterior end and an opening surrounded by a thickened ring at anterior end through which extends one flagellum that is about twice as long as the lorica; cell very small, diameter of lorica 6 microns.

USE OF KEY FOR IDENTIFICATION OF ALGAE

In order to use the key, first observe the specimen and determine its essential characteristics. Referring to the key, lines 1a and 1b at the beginning are then compared to one another and with the essential characteristics of the specimen. At the end of the line which agrees with the specimen is a number. Turn to the place in the key where this same number is listed on the left hand side of the page and is divided into lines a and b. Repeat the above process and continue until a name for the alga rather than an additional number is given at the end of the line. Thus, in determining the name of Example No. 1 above, lines from the key are selected until line 334b is reached, giving the species name for the alga. The appropriate lines are as follows: 1b, 2b, 3b, 262b, 263b, 268b, 269b, 276b, 278b, 297b, 298b, 299b, 307b, 308b, 311b, 315b, 317b, 318b, 325b, 326b, 328b, 329b, 330b, 331b, 332b, 333b, 334b *(Chlorella pyrenoidosa)*.

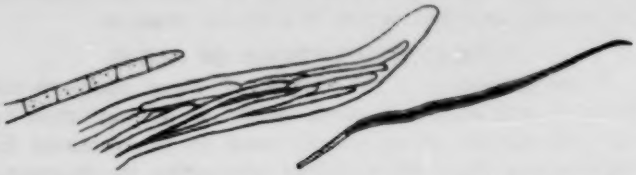


Figure 19.—*Microcoleus paludosus*, showing a single thread and a group of threads surrounded by a sheath, under high and low magnification.

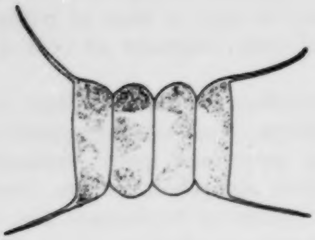


Figure 20.—*Scenedesmus quadricauda*, showing spine-like extensions on the terminal cells.

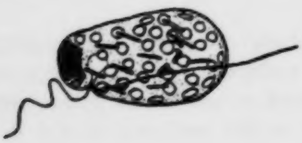


Figure 21.—Lateral flagella in *Merotrichia capitata*.

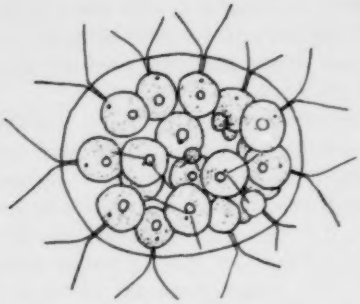


Figure 22.—Anterior flagella on cells of *Pleodorina illinoisensis*.

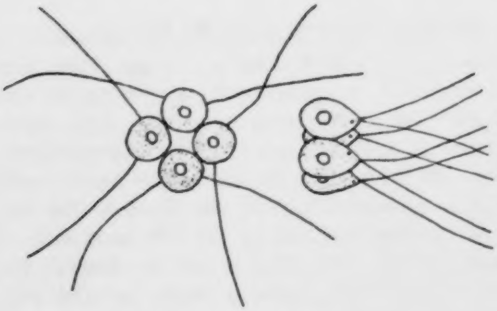


Figure 23.—Posterior and lateral views of anterior flagella on *Gonium sociale*.

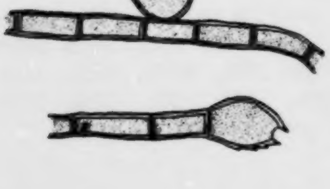


Figure 24.—Two spore-producing cells on filaments of *Trentepohlia aurea*.

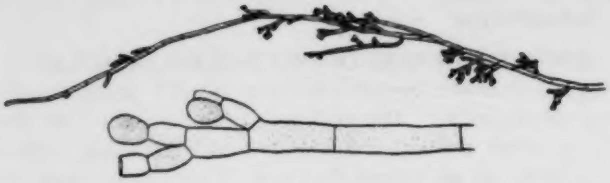


Figure 25.—Enlarged terminal reproductive cells on filaments of *Audouinella violacea*.

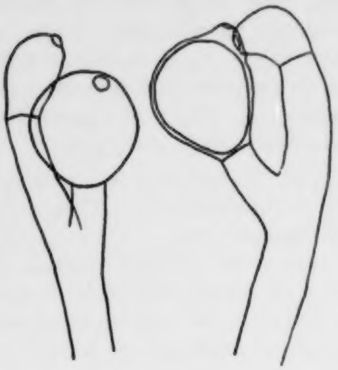


Figure 26.—Terminal cells specialized for sexual reproduction in *Vaucheria arechavaletae*.

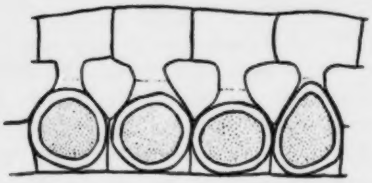


Figure 27.—Thick-walled zygospores formed during sexual reproduction in *Zygnema normani*.

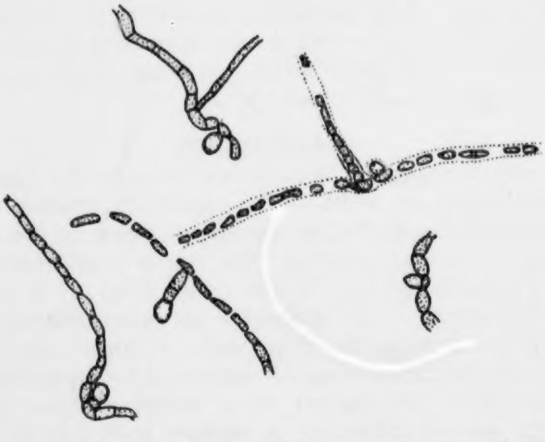


Figure 28.—True branching in the blue-green alga, *Nostochopsis lobatus*.

When a name has been reached in the key, reference can then be made to illustrations and descriptions of that particular genus or species in this and other manuals to determine whether the specimen seen under the microscope is correctly identified. Three manuals on algae in water supplies have been published abroad, one in Danish (20), one in Japanese (21), and one in German (22).

REFERENCES

1. Suggested classification of algae and protozoa in sanitary science. C. M. Palmer and W. M. Ingram. Sewage and Indust. Wastes 27:1183-1188. 1955.
2. The fresh-water algae of the United States. Ed. 2, G. M. Smith. McGraw-Hill, N.Y., 719 p. 1950.
3. A treatise on the British freshwater algae. New and revised ed. G. S. West and F. E. Fritsch. Univ. Press, Cambridge, England, 534 p. 1927.
4. Revision of the coccoid Myxophyceae. F. Drouet and W. A. Daily. Butler Univ. Bot. Stud. 12:1-218. 1956.
5. The Characeae of Indiana. Fay K. Daily. Butler Univ. Bot. Stud. 11:5-49. 1953.
6. Nomenclatural changes in two genera of diatoms. Ruth Patrick. Notulae Naturae, Acad. Natural Sci. Philadelphia, No. 28, 11 p. 1939.
7. Synopsis of North American Diatomaceae. Part II, Naviculatae, Surirellatae. C. S. Boyer. Proc. Acad. Natural Sci. Philadelphia 79:229-583. 1927.
8. The genus *Euglena*. Mary Gojdics. Univ. Wis. Press, Madison, Wisc., 268 p. 1953.
9. The algae of Illinois. L. H. Tiffany and M. E. Britton. Univ. Chicago Press, Chicago, Ill., 407 p. 1952.
10. A preliminary study of the algae of northwestern Minnesota. F. Drouet. Proc. Minnesota Acad. Sci. 22:116-138. 1956.
11. Algae of the western Great Lakes area. G. W. Prescott. Cranbrook Inst. Sci., Bloomfield Hills, Mich., Bull. 31, 946 p. 1951.
12. Bacillariophyta (Diatomeae). F. Hustedt. Heft 10 in A. Pascher, Die Süsswasser-Flora Mitteleuropas. Gustav Fisher, Jena, Germany, 466 p. 1930.
13. The marine and fresh-water plankton. C. C. Davis. Mich. State Univ. Press, East Lansing, Mich., 562 p. 1955.
14. Revision of the classification of the Oscillatoriaeceae. F. Drouet. Monograph 15, Acad. Natural Sci. Philadelphia, 370 p. 1968.
15. Revision of the Nostocaceae with cylindrical trichomes. F. Drouet. Hafner Press, Riverside, N.J., 256 p. 1973.
16. Algae of importance in water supplies. Plans for a manual with keys and color plates. C. M. Palmer and H. J. Walter. News Bull., Phycological Soc. Amer. 7 (No. 21):6-7. 1954.
17. Algae of importance in water supplies. C. M. Palmer and C. M. Tarzwell. Public Wks. Mag. 86 (No. 6):107-120. With 6 color plates. 1955.
18. Algae of Marion County, Indiana. A description of thirty-two forms. C. M. Palmer. Butler Univ. Bot. Stud. 2:1-21. 1931.
19. Additional records for algae, including some of the less common forms. C. M. Palmer. Butler Univ. Bot. Stud. 5:224-234. 1942.
20. Dansk Planteplankton. G. Nygaard. Gyldendalske Boghandel Nordisk Forlag, Copenhagen, Denmark, 52 p. 1945.
21. The easy classification of important microorganisms in Japanese water supplies. S. Kawakita. Jour. Japanese Waterwks. and Sewerage Assn., Nos. 251, 253, 257, 258, 263, 265. 1955-56. (In Japanese.)
22. Das Phytoplankton des Süsswassers. G. Huber-Pestalozzi. Band 16, Teil 1-4. In Die Binnengewässer by A. Thienemann. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, Germany. 1938-55.

TABLE 1. COMPARISON OF THE FOUR MAJOR GROUPS OF ALGAE IN WATER SUPPLIES

	Algae groups			
Characteristics	Blue-green algae	Green algae	Diatoms	Pigmented flagellates
Color	Blue-green to brown	Green to yellow-green	Brown to light green	Green or brown
Location of pigment	Throughout cell	In plastids	In plastids	In plastids
Starch	Absent	Present	Absent	Present or absent
Slimy coating	Present	Absent in most	Absent in most	Present or absent
Cell wall	Inseperable from slimy coating	Semirigid smooth or with spines	Very rigid, with regular marking	Thin, thick or absent
Nucleus	Absent	Present	Present	Present
Flagellum	Absent	Absent	Absent	Present
Eye spot	Absent	Absent	Absent	Present

TABLE 2. ALGAE IN WATER SUPPLIES: A LIST OF THE MORE IMPORTANT SPECIES

Key to Columns:

1. Alga name.
2. *Group:* D, diatom; G, green; BG, blue-green; YG, yellow-green; B, brown; R, red; Fl, flagellate; De, desmids.
3. *Significance:* A, attached; C, clean; E, eutrophication; F, filter; I, indicator; PE, pollution, estuarine; PF, pollution, fresh; Pl plankton of lakes; SP, sewage pond; St, stream; T, taste and odor.
4. Plate number or figure number.

1	2	3	4
Achnanthes:	D		59
lanceolata			
microcephala			II
minutissima			
Achnanthidium breviceps var. intermedia	D		
Acrochaetium thuretii	R	PE	
Acrochaetium virgatulum		PE	
Actinastrum:	G	E,Pl,SP,St	33
gracillimum		Pl	
hantzschii		PF,Pl	
Agardhiella tenera	R	PE	V
Agmenellum:	GB	E,SP,St	
quadriduplicatum		C,PF	III,IV,9
Amphidinium fusiforme	Fl	PE	V
Amphiprora alata	D		
Amphora:	D		
acutissima		PE	
ovalis		C	
Anabaena:	BG	E,SP,St,T	30
circinalis		T	
constricta		PF	IV,13
flos-aquae		F,Pl	VIII
planktonica		T	VII
Anabaenopsis	BG	SP	
Anacystis	BG	E,I,Sp,St	29
cyanea		I,T,Pl	VII,8
dimidiata		F	VIII
montana		A,PF	IV
thermalis		Pl	
Ankistrodesmus:	G	E,I,SP,St	
falcatus		PF,Pl,SP	VI,35
var. acicularis		C	III
Anomoeoneis exilis	D		
Aphanizomenon flos-aquae	BG	E,SP,St,T	VII
Apicoccus	G	SP	

1	2	3	4
Arthrospira jenneri	BG	E,PF,SP	IV
Asterionella:	D	E	37
formosa		E,F	VIII
gracillima		T	VII
japonica		PE	V
Audouinella violacea	R	A	II,25
Bacillaria paradoxa	D		
Batrachospermum:	R	St	
moniliforme		A	II
vagum		C	
Biddulphia laevis	D		
Botryococcus braunii	G	Pl	I
Bulbochaete:	G		
insignis		A	II
mirabilis		C	
Caloneis	D	St	
Calothrix:	BG	E,SP	44
braunii		A	
parietina		C	III,48
Carteria multifilis	Fl	I,PF	IV
Ceramium	R	E	
Ceratium hirundunnella	Fl	E,F,Pl,T	VII
Chaetoceros decidiens	D	PE	V
Chaetophora	G	ST	
Chaetomorpha area	G	PE	V
Chaetopeltis megalocystis	G	C	
Chaetophora:	G		
attenuata		A	
elegans		A	II
Chara:	G		
globularis		A	II
vulgaris		T	
Characium	G	SP	
Chlamydomonas:	Fl	I,PE,SP,St,T	60
globosa		T	
pertusa		SP	VI
reinhardi		PF	VI
Chlorella:	G	I,E,SP,St	
ellipsoidea		Pl	
pyrenoidosa		F,PF	VIII
vulgaris		PF	IV
Chlorococcum humicola	G	PF,SP,St	IV
Chlorogonium:	Fl	SP	
elongatum		PF	
euchlorum		PF	IV,69
Chodatella quadriseta	G	SP,St	VI
Chromulina:	Fl	SP,St	
rosanoffii		C	III
vagans		SP	VI
Chroomonas:	Fl	PE,SP	
caudata		SP	VI
nordstetii		C	
setoniensis		C	
Chrysamoeba	YG	SP	
Chrysidiastrum	YG	E	
Chrysococcus:	YG	St	
major		C	
ovalis		C	
refescens		C	III
Chrysosphaerella longispina	Fl	T	
Cladophora:	G	A,E,SP,St	
aegagropila		F	
crispata		A	II
fracta		Pl	
glomerata		A,C	III
insignis		T	
profunda var. nordstedtiana		A	
Closteridium	G	SP	
Closteriopsis brevicula	G	SP	VI
Closterium:	De	E,I,SP,St	62
acerosum		PF	
aciculare		Pl	
actum		SP	VI
minoliferum		F	VIII
Coccochloris stagnina	BG	C	III
Cocconeis:	D	I,St	
pediculus		A	
placentula		C,PF	III
Codium fragile	G	PE	V
Coelastrum microporum	G	E,PF,Pl,St	I
Compsopogon coeruleus	R	A	II,18
Coscinodiscus:	D	PE	
denarius		Pl	
rothii		Pl	
Cosmarium:	De	E,SP	
botrytis		SP	VI
portianum		T	
Crucigenia quadrata	G	Pl,SP,St	
Cryptoglena pigra	Fl	PF	
Cryptomonas:	Fl	SP,T	60
cylindrica		SP	VI
erosa		PF,T	
Cyanomonas	Fl	SP	
Cyclotella:	D	E,I,SP,St	37
atomus		Pl	
bodanica		C	III
comta		Pl,T	
glomerata		Pl	
kutzingiana		Pl	
meneghiniana		F,PF	VIII
ocellata		Pl	
pneudostelligera		Pl	
stelligera		Pl	
striata		Pl	
Cylindrospermum:	BG		
musicola		T	
stagnale		Pl	I
Cymatopleura solea	D	Pl,SP	
Cymbella:	D	SP,St	
cesati		C	
prostrata		A	II
pusilla		PE	
tumida		Pl	
turgida		Pl	
ventricosa		F	VIII
Denticula wipplingeri	D	PE	
Dermocarpa	BG	SP	
Desmidium grevillii	De	Pl,SP	I
Diacanthos belenophorus	G	SP	VI
Diatoma:	D	E	
anceps		Pl	
elongatum		St	
vulgare		F,PF,Pl,St	VIII
Dichotomosiphon tuberosus	G	A,F	
Dictyosphaerium:	G	SP,St	
ehrenbergianum		SP,T	VI
pulchellum		F,Pl	
Dinobryon:	Fl	SP,T	60
divergens		Pl,T	VII
sertularia		F	VIII
sociale		Pl	
stipitatum		C	
Dimorphococcus lunatus	G	A	
Diploneis smithii	D	St	
Dispora	G	SP	
Draparnaldia:	G	St	
glomerata		A	II
plumosa		C	
Dunaliella	Fl	PE,SP	
Elakatothrix gelatinosa	G	SP	VI
Enteromorpha intestinalis	G	A,SP,PE	45,V
Entophysalis lemaniae	BG	C,I	III
Epithemia:	D	SP	
sorex		Pl	
turgida		A	
Euastrum oblongum	De	C,Pl	I
Eudorina elegans	Fl	Pl,PF,SP	I
Euglena:	Fl	E,I,St,SP	58,60
acus		PF	
agilis		PF	

1	2	3	4
deses		PF	
ehrenbergii		C	
gracilis		Pl,PF	I
oxyuris		Pl	
polymorpha		PF	
sanguinea		T	
spirogyra		C	
viridis		PF	IV
Eunotia:	D	Pl	
lunaris		Pl	
pectinalis		Pl	
Eutreptia:	Fl	PE	
lanowii		I	
viridis		PE	V
Fragilaria:	D	E,SP	37
brevistriata		Pl	
capucina		Pl	I
construens		T	
crotonensis		E,Pl,St,F	VIII
leptostauron		Pl	
pinnata		Pl	
Frustulia vulgaris	D	Pl,SP	
Glenodinium palustre	Fl	E,SP,St,T	
Gloeocystis:	G	E,SP	
gigas		A	
planktonica		T	
Gloeotrichia:	BG		
echinulata		F	
natans		Pl	36
Golenkinia radiata		Pl,SP,St	VI
Gomphoneis	D	Pl	
Gomphonema:	D	I,SP,St	
geminatum		A	II
olivaceum		A,St	
parvulum		I,PE,PF	IV
Gomphosphaeria:	BG	E,SP	
aponina		Pl	
lacustris		Pl,A	VII
Gonium pectorale	Fl	Pl,SP	23,60
Gynodinium	Fl	PE,SP,St	
Gyrosigma:	D	E	
attenuatum		C,Pl	
kutzingii		Pl	
Haematococcus	Fl	SP	II
Hantzschia amphioxys	D	PF,SP	
Hemidinium	Fl	SP	
Heterocapsa	Fl	PE	
Hildenbrandia rivularis	R	C,St	III
Hyalotheca mucosa	De	Pl	
Hydrodictyon reticulatum	G	A,E,T,F	VII,2
Hydrurus	YG	C	17
Johannesbaptistia	BG	SP	
Katodinium	Fl	PE	
Kirchneriella:	G	SP	
lunaris		Pl	
subsolitaria		I	
Lemanea annulata	R	C,St	III
Lepocinclis:	Fl	I,SP,St	
ovum		PF	
texta		PF	IV
Lyngbya:	BG	E,SP	63
aestuarii		A	
digueti		PF	IV
lagerheimii		A	II
ocracea		A	
putealis		A	
versicolor		Pl	
Mallomonas caudata	Fl	C,Pl,SP,T	VII
Massartia vorticella	Fl	SP	VI
Melosira:	D	E,I	37,56
ambigua		Pl,St	
binderana		Pl	
crenulata		Pl	
distans var. alpigena		Pl	
granulata		F,Pl,PF,St	VIII
granulata var. angustissima		Pl	
islandica		Pl	
italica		E,Pl	
sulcata		PE	V
varians		F,PF	
Meridion circulare	D	C	III
Micractinium pusillum	G	E,I,PF,Pl, St,SP	I
Micrasterias truncata	De	C	III
Microcoleus subtorulosus	BG	C,PE	III,19
Microspora:	G	SP	
amoena		A	II
wittrockii		A	
Mougeotia:	G	A,E	
genuflexa		Pl	
scalaris		Pl	I
sphaerocarpa		F	
Nannochloris atomus	G	PE,SP	V
Navicula:	D	E,I,PE,SP,St	
accomoda		I	
canalis		Pl	
confervacea		Pl	
contenta		Pl	
cryptocephala		PF	
exigua var. capitata		C	
graciloides		T	VIII
hartii		PE	
hungarica		Pl	
incomposita		Pl	
lanceolata		F	
mutica		Pl	
notha		Pl	
radiosa		Pl	
sydowii		PE	
tripunctata		Pl	
viridula		PF	
Nitella:	G		
flexis		A	
gracilis		T	VII
Nitzschia:	D	E,I,SP,St	
acicularis		PF	
amphibea		Pl	
closterium		PE	V
denticula		Pl	
dissipata		Pl	
fonticula		Pl	
holsatica		Pl	
hungarica		Pl	
linearis		A,C	
palea		A,I,PF,F	IV
parvula		Pl	
sigma		Pl	
sigmoidea		PF,Pl	
tryblionella		Pl	
Nodularia spumigena	BG	Pl	1,64
Nostoc:	BG		
carneum		Pl	
pruniforme		A	
Ochromonas	Fl	SP	
Oedogonium:	G	A,I,SP	46
boscii		A	
grande		A	
idioandrosporum		Pl	
suecicum		A	II
Olithodiscus	Fl	PE	
Oocystis:	G	E,SP,St	32,12
borgei		Pl	I
lacustris		Pl	
Ophiocytium capitatum	G	Pl	
Oscillatoria:	BG	E,I,SP,St	31
agardhii		Pl	
amphibia		A,F	
chalybea		A,F,PF	VIII
chlorina		PF	IV
curviceps		T	

1	2	3	4
formosa		PF	
lauterbornii		PF	IV
limosa		PF	50
ornata		F	
princeps		A,F,PF	VIII,52
pseudogeminata		F	
putrida		PF	IV
rubescens		F,I	
splendida		F,PF	VIII
tenuis		A,PF	51
Ourococcus bicaudatus	G	SP	VI
Palmella mucosa	G	A,F,SP	VIII
Palmellococcus	G	SP	
Pandorina morum	Fl	E,I,Pl,SP,T	VII,57
Pediastrum:	F	E,SP,St	
boryanum		PF,Pl	I,6
duplex		Pl	68
tetras		T	
Pedinopera	Fl	SP	
Pelvetia fastigiata	B	PE	V
Peridinium:	Fl		55
cinctum		T	VII
triquetum		I	
trochoideum		PE	V
wisconsinense		F	
Phacotus lenticularis	Fl	C,St	III
Phacus:	Fl	I,SP,St	
longicauda		C	
pleuronectes		PF,Pl	I
pyrum		PF	IV
Phormidium:	BG	A,F,I,SP,ST	
autumnale		PF	IV
inundatum		A,C	
retzii		A, Pl	
subfuscum		A	
uncinatum		A,PF	II,53
Phytoconis botryoides	G	A,E	II,10
Pinnularia:	D	SP	
nobilis		C	III
subcapitata		C	
Pithophora oedogonia	G	A	41
Planktosphaeria	G	SP	VI
Plectonema tomasiniana	BG	Pl	
Pleodorina	Fl	SP	22
Pleurogaster	YG	SP	
Pleurosigma:	D	Pl	
delicatulum		Pl	
salinarum		PE	
Polyedriopsis spinulosa	G	SP	VI
Polysiphonia	R	PE	
Porphyra atropurpurea	R	PE	V
Prasiola:	G	A	
nevadense		A	
stipitata		PE	V
Prorocentrum	Fl	PE	V
Pteromonas angulosa	Fl	SP	VI
Pyrobotrys:	Fl	SP	
gracilis		PF	
stellata		PF	IV
Raphidiopsis	BG	SP	
Rhizoclonium hieroglyphicum	G	A,C,St	III
Rhizosolenia:	D	PE	37
eriensis		Pl	
gracilis		Pl	
Rhodoglossum affine	R	PE	V
Rhodomonas lacustris	Fl	C,SP	III
Rhoicosphenia curvata	D	A	
Rhopalodia:	D		
gibba		Pl	
musculum		PE	
Rivularia:	BG	E	
dura		F	VIII
haematites		T	
Sacheria	R	St	
Scenedesmus:	G	E,I,SP,St	34
abundans		T	
bijuga		Pl	
dimorphus		P,SP	VI
obliquus		PF	67
quadricauda		PF,Pl	I
Schizomeris leibleinii	G	A	41
Schizothrix calcicola	BG	SP	VI
Schroederia setigera	G	Pl,SP	VI
Scytonema tlypothricoides	BG	Pl	
Scytosiphon lomentaria	B	PE	V
Selenastrum:	G	I,SP	
capricornutum		I	
gracile		Pl	
Sirogonium	G	A	
Skeletonema costatum	D	PE	V
Sphaerellopsis	Fl	SP	
Sphaerocystis schroeteri	G	E,Pl,SP	I
Spirogyra:	G	A,E,SP	3,4
communis		PF	IV
fluviatilis		Pl	
majuscula		T	
porticalis		F	VIII
varians		Pl	
Spirulina:	BG	E,SP	
major		A,PE	V
nordstedtii		Pl	
subtilissima		SP	VI
Spondylomorum quaternarium	Fl	PF	
Staurastrum:	De	E,SP,St	
paradoxum		T	VII
polymorphum		Pl	
punctulatum		C	III
Stauroneis phoenicenteron	D	Pl,SP	I
Stephanodiscus:	D	E	
astraea		E	
astraea var. minutula		Pl	
binderanus		F	
dubius		Pl	
hantzschii		F,PF,Pl,St	I
niagarae		T	
niagarae var. magnifica		Pl	
tenuis		Pl	
Stephanoptera gracilis	Fl	PE	V
Stichococcus:	G	SP	
bacillaris		PF	
marinus		PE	V
Stigeoclonium:	G	A,I,SP,St	47
lubricum		A	II
stagnatile		Pl	
tenue		I,PF	IV
Stigonema minutum	BG	A	42
Surirella:	D	E,SP,St	
angustata		Pl	
brightwellii		Pl	
ovata		PF	
splendida		C	III
striatula		Pl	
Symploca muscorum	BG	T	13
Synedra:	D	E,I,SP,St,T	37,55
acus		F,PF	VIII
var. angustissima		C	
var. radians		F	
capitata		Pl	
hartii		PE	
nana		Pl	
pulchella		F	
tabulata		PE,Pl	
ulna		PF,T	VII
vaucheriae		Pl	
Synura uvella	Fl	Pl,PF,T	VII
Tabellaria:	D	E,F,St,T	37
fenestrata		F,T	VII
flocculosa		F	VIII
Tetradesmus	G	SP	

1	2	3	4
Tetraedron:	G	SP	
limneticum		Pl	
muticum		PF	IV
Tetraspora gelatinosa	G	A,St	II,43
Tetrastrum	G	SP	
Thorea ramosissima	R	A	
Tolypothrix tenus	BG	A	II
Trachelomonas crebea	Fl	F,SP,St	VIII,66
Tribonema:	YG	E	
bombycinum		F	VIII
minus		Pl	
Trichodesmium erythraeum	BG	PE	V
Ulothrix:	G	E,SP,St	
aequalis		C	III
tenerrima		Pl	
variabilis		F	
zonata		A,C,PF	II,49
Ulva lactuca	G	PE	V
Uroglenopsis americana	Fl	SP,T	VII,60
Vacuolaria novo-munda	Fl	SP	VI
Vaucheria:	G	A,F,St	26
geminata		A,C	38
sessilis		A	II,39
terrestris		Pl	
Volvox aureus	Fl	E,Pl,T	VII
Zoochlorella	G	SP	
Zygnema:	G	A,SP	27
insigne		F	
pectinatum		Pl	
sterile		Pl	I

TABLE 3. RECENT CHANGES IN NAMES OF ALGAE

Old name	New name
Aphanocapsa	Anacystis
Aphanothece	Coccochloris
Chamaesiphon	Entophysalis
Chamaesiphon incrustans	Entophysalis lemaniae
Chantransia	Audouinella
Chara fragilis	Chara globularis
Chlamydobotrys	Pyrobotrys
Chroococcus	Anacystis
Chroococcus limneticus	Anacystis thermalis
Chroococcus turgidis	Anacystis dimidiata
Clathrocystis	Anacystis
Coelosphaerium	Gomphosphaeria
Coelosphaerium kuetzingianum	Gomphosphaeria lacustris
Coelosphaerium naegelianum	Gomphosphaeria wichurae
Encyonema	Cymbella
Encyonema paradoxum	Cymbella prostrata
Euglena pisciformis	Euglena agilis
Gloecapsa	Anacystis
Gloecapsa conglomerata	Anacystis montana
Gloeothece	Coccochloris
Gloeothece linearis	Coccochloris peniocystis
Gomphosphaeria naegeliana	Gomphosphaeria wichurae
Holopedium	Microcrosis
Lagerheimia	Chodatella
Merismopedia	Agmenellum
Merismopedia glauca	Agmenellum quadriduplicatum
Merismopedia tenuissima	Agmenellum quadriduplicatum
Microcystis	Anacystis
Microcystis aeruginosa	Anacystis cyanea
Odontidium	Diatoma
Oedogonium crassiusculum var. idioandrosporum	Oedogonium idioandrosporum
Polycystis	Anacystis
Polycystis aeruginosa	Anacystis cyanea
Protococcus	Phytoconis
Protococcus virdis	Phytoconis botryoides
Sphaerella	Haematococcus
Spirulina jenneri	Arthrospira jenneri
Synechococcus	Coccochloris
Synedra delicatissima	Synedra acus var. radians

CHAPTER IV

ALGAE IN STREAMS

A stream affects its algal flora in a number of ways which are different from lakes. The flow of water in a stream is constantly subjecting any area to a passing mass of water causing all ingredients to be resupplied to that area from the water upstream. Turbulence in a stream is almost always sufficient to prevent the formation of stratification such as we find in lakes. This is one of the most important differences between a stream and a lake. Even when a river is deep, there tends to be a condition of complete circulation (1). The stream bottom affects the condition of the water constantly and in many ways. It is releasing or receiving materials from the water, including silt, minerals, alkalies, acids, nutrients, and living or dead organisms or organic debris. The exchange of materials varies with the geologic nature of the bottom, the depth and rate of flow of the water, the temperature, and other factors. A stream also contains a mixture of the waters from its tributaries, which may often be quite different from one another. Contours of the stream channel change from place to place; shallow flowage and backwater alternate with swift water and with deep pools. Current velocities vary. Different geological formations may follow one another in quick succession. Clean, hard bottoms may give way to soft mud deposits and *vice versa*. Wastewaters from human habitations and industries bring about sudden and often catastrophic changes. Stream levels rise and fall according to the amount of rainfall (2). Thus, conditions in a stream tend to be very unstable at any location, in this way also making it different from a lake.

Streams are rarely entirely destitute of raw materials, as may be the case in some lakes, and probably on the whole are better supplied with nitrogenous compounds (3). Streams undefiled by anything other than natural enrichment will contain at most only a few ppm of CO_2. This is one of the reasons why they fail to develop large crops of algal growths (2). There is little correlation between the seasonal flux in chemical conditions and the seasonal condition of plankton production.

Stream temperature affects plankton profoundly. Below 45°F the plankton content of the Illinois River falls to about 9 percent of that present at higher temperatures. Light is as important in streams as it is in lakes, but light in streams may more often be reduced due to greater turbidity. Turbidities of more than 30 ppm are high enough to cut off sunshine almost completely except for a shallow layer very close to the surface (2). Although some plankton occur even in very muddy streams, turbidity usually seems to be the major limiting factor in algal growth (4). Wind action appears to be of little significance in streams. Area and depth of a stream show little relation to plankton production (2). Speed of the current and the nature of the bottoms are the factors which most affect the plants and animals of a stream. But for most organisms, small, local variations, such as the difference in the current at the edge and in the middle of the stream, are more important than the general condition (5).

Attached algae in fast currents take full advantage of the water in their reproduction. Due to the mixing caused by the current, these algae are able to disperse their reproductive units into a high percentage of rock fissures, cracks, scratches, and roughened areas to permit subsequent growth from the colonizing cells to cover almost all of the available surfaces. *Gomphonema olivaceum* and *Diatoma vulgare* are examples of diatoms that can quickly spread to additional rock surfaces, especially during the cold water period from late November to early April (6).

The complete stream has three horizontal areas:

1. The upper or mountain course, with swift current, especially after a rain. Stones are rolled along the bottom. Its valley is V-shaped, with unstable banks. However, some streams may arise instead from springs, lakes, or from drainage of low-lying land.

2. The middle course is located over the foothills. It has lost some of its velocity but is still rapid enough to carry sand, silt, and mud in suspension and to roll pebbles. Its main work is transportation. Its valley has a broad, open section, stable sides, and less erosion than in the first area.

3. The lower course meanders lazily over a plain. It has lost much of its velocity and much of its power of transportation. It lays down part of its load as beaches, sand banks, and large flat plains of deposition, spreading aluvium over a wide flood plain or delta (5).

The algae, especially of swift running streams, are more distinctive than those of any other type of aquatic habitat and include a larger percentage of genera and species restricted to that particular habitat (7). In swift water the characteristic algae are those with holdfast cells or similar structures. The freshwater red algae *Lemanea* and *Sacheria* grow in rapid torrents and waterfalls. *Batrachospermum* develops attached in cool, slightly alkaline, rapid waters of small streams. The most common attached alga in temperate zone streams is *Cladophora*, often extending many feet with the current. In very shallow waters flowing from springs, *Vaucheria* grows attached, forming large mats. *Tetraspora, Draparnaldia,* and *Chaetophora* are common early spring forms in rapidly moving waters which are well supplied with nitrogen and phosphorus compounds (3). In this rushing water of the rapids, the stones are thickly overgrown with mosses and algae. Diatoms which attach themselves to stones by means of gelatinous masses or stalks include *Achnanthes, Cocconeis, Cymbella,* and *Gomphonema* (8). Stones in lakes, on the other hand, exhibit much smaller growths (1). Other algae without holdfast cells may be present on various substrata, in spite of the current, due to copious secretion of mucus in which the cells are imbedded. Attached and unattached desmids, diatoms, blue-green and green algae are often present (3). Thus, in the swift current are found encrusting algae such as *Hildenbrandia,* attached algae in which the greater part projects into the current, and algal forms held in place by the mucus (7).

During the winter, ice is responsible for scouring attached algae from rocks and other bottom materials. Anchor ice may form in the beds of rapid streams. The surface water may not freeze because of its motion, but freezing may occur on the bottom where the current is retarded. It congeals in semi-solid flocculent masses which, when attached to the stones, often bring them up and cause them to be carried away. Thus, the organisms in the stream bed are deprived of their shelter and exposed to new perils (9).

The algae of areas of slower current are for the most part unattached forms behaving as planktonic algae. These are, in general, distinct from those of ponds and lakes and are often designated by the terms potamoplankton or rheoplankton (3). Since the possibilities of a good seed bed are more remote than in lakes and ponds, the streams depend upon their tributaries, backwaters, and ox-bows for the source of most of their plankton. The plankton that has become entirely adapted to river conditions is much less rich in species than is the truly limnetic plankton. The multiplication of the algal constituents, whatever the source, may take place as they are carried downstream. In general the less rapid the stream the greater the number of plankton. Slow-moving areas in streams may often be covered with blooms in summer, in many instances, unialgal growths of *Chlamydomonas, Euglena,* diatoms, or blue-green algae (3). Unattached, filamentous algae may form mats or blankets.

The current is slower at the bottom, around stones, and along the sides of the stream. Many algae increase in these areas of slow current, and some of them move into the area of faster current (9). In lakes and ponds the algae for the most part are ones not found in the benthos. In streams there is a greater variety of microscopic organisms in the littoral environment than in the channel proper.

The areas adjacent to the shores do not have any uniformity of plankton. Even here the ever-changing cross-section of a stream does not permit the development of as characteristic a littoral flora and fauna as is found along the shores of lakes and reservoirs (2).

The stream plankton is thus seeded with a great range and variety of organisms. It is not characterized by any species peculiar to it, nor by any precise assemblages of eulimnetic organisms. It is subject to extreme fluctuations in quantity and constitution. The plankton production appears to exhibit a series of recurrent pulses which vary from 3 to 5 weeks in duration (2).

Normally, most of the growth of algae in the stream is planktonic. The planktonic organisms are usually dominated by rotifers and diatoms. There is a marked tendency of green algae and blue-green algae to appear in the warm months. When streams are enriched, certain types of algae tend to occur in great abundance. These include *Stigeoclonium, Cladophora, Ulothrix, Rhizoclonium, Oscillatoria, Phormidium, Gomphonema, Nitzschia, Navicula,* and *Surirella,* all of which may be found in unenriched streams but far less abundantly. We do not know why these particular genera are encouraged while others are not. *Cladophora* growths appear to be stimulated by the addition of phosphate to the water (4).

In the United States, the Southeast, the Northeast, the Southwest, and the upper and lower Mississippi River each have their characteristic diatom floras. Many individual rivers have characteristic plankton. Diatoms found in large numbers in all major drainage basins of the United States are *Diatoma vulgare, Fragilaria crotonensis, Melosira ambigua, Melosira granulata,* and *Stephanodiscus hantzschii. Astereonella formosa* and *Diatoma elongatum* become abundant during cold water seasons. Other common diatoms of streams would include *Achnanthes, Caloneis, Cocconeis, Cyclotella, Cymbella, Diploneis, Gomphonema, Navicula, Nizschia, Surirella, Synedra,* and *Tabellaria.* The common blue-green algae, green algae, and pigmented flagellates of streams would include the forms listed in table 4 (10). Six of these algae are shown in figures 29-34.

The total number of species for any river varied from about 70 to 140 in a study made of nine streams in the eastern United States. The mean for all of these rivers was 84, for the soft water ones, 89, and the hard water ones, 78. Approximately 56 percent of the species were found in only one river and 73 percent occurred in one or two rivers. Less than 1 percent of the species occurred in all the rivers studied (11).

The impression concerning the abundance of algae in streams has changed in recent years. Formerly, the unattached algae were considered to be so few that often they were recorded in numbers per liter or cubic meter rather than per ml. In such data, when converted to numbers per ml, the algae are generally recorded as fewer than 100. In 1957 the National Water Quality Network program was inaugurated by the Public Health Service. Sampling stations on 16 rivers were chosen where water samples were obtained at regular intervals for examination. The number of sampling stations was soon increased to include other rivers, and the program was continued for several years (12).

Over a period of 2 years the average count was 3,625 algae per ml. April, September, and October had the highest counts. Some individual counts exceeded 20,000. The five rivers with the highest average counts for the first year were the Mississippi, Arkansas, Merrimack, Missouri, and Columbia while the five with the lowest were the Red,

Figure 29.—*Anacystis (Microcystis).*

Figure 32.—*Oocystis.*

Figure 30.—*Anabaena.*

Figure 33.—*Actinastrum.*

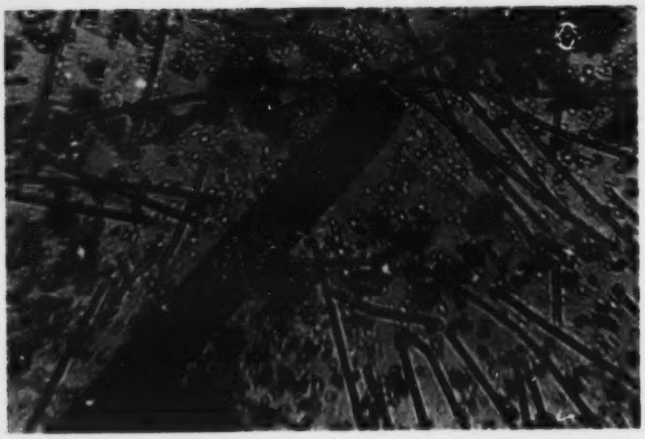


Figure 31.—*Oscillatoria* (two sizes).

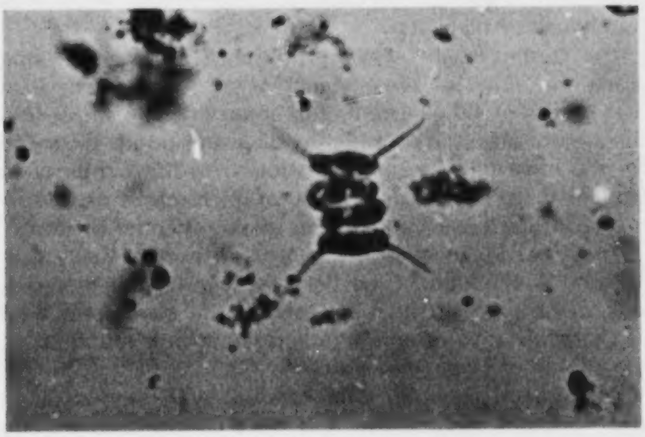


Figure 34.—*Scenedesmus* (reproducing).

Detroit, Colorado, Savannah, and Tennessee Rivers (12). Records compiled for the Public Health Service have been published covering a period from October 1, 1957, to September 30, 1963 (13). In addition, an account of the principal diatoms of the major waterways of the United States has been published (14) and one on plankton population dynamics (10).

Concern for the quality of river waters increases as the many uses for these waters are intensified. It is necessary to know the algal population of streams quantitatively and qualitatively, if we are to be concerned with assessing their value or their significance as stream purifiers, pollution indicators, or as producers of excessive growths, their role in water treatment problems, and their function as the primary food producers for fish. It can be important to know the algal population of a river before any major change is made in the use of the stream. Also, we need to know the algal population of rivers throughout the year and not merely for the warmer months. Determination of the effect of particular factors on the biota of rivers will require detailed studies that should be planned for that particular purpose (12).

REFERENCES

1. The communities of running water. F. Ruttner. In Fundamentals of Limnology by F. Ruttner. University of Toronto Press, p. 198-210. 1953.
2. Rheology. Chapter XI in The Microscopy of Drinking Water, 4th ed., by G. C. Whipple, G. M. Fair, and M. C. Whipple. J. Wiley & Sons, N.Y., p. 282-312. 1948.
3. Algae of streams and rivers. Chapter V in Algae, the Grass of Many Waters, by L. H. Tiffany. Charles C. Thomas, Springfield, Ill., p. 57-64. 1938.
4. The enrichment of streams. In Eutrophication: Causes, Consequences, Correctives by H. B. N. Hynes. Proc. Symposium, National Acad. Sci., Washington, D.C., p. 188-196. 1967.
5. Rivers. Chapter 5 in Life in Lakes and Rivers by T. T. Macan and E. B. Worthington. Collins, London, p. 62-78. 1951.
6. The influence of water currents on the life functions of algae by J. Blum. Ann. New York Acad. Sci. 108:353-358. 1963.
7. The algae of different types of habitat. In the Fresh-Water Algae of the United States, 2nd ed., by G. M. Smith. McGraw-Hill Book Co., N.Y., p. 17-26. 1950.
8. Water habitats. In The Diatoms of the United States by R. Patrick and C. W. Reimer. Academy of Natural Sciences of Philadelphia. Monograph No. 13. p. 39-44. 1966.
9. Streams. In The Life of Inland Waters by J. G. Needham and J. T. Lloyd. Amer. Viewpoint Society, New York, p. 77-88. 1928.
10. Plankton population dynamics. L. G. Williams. U.S. Public Health Publication No. 663. National Water Quality Network-Supplement 2, 90 p. 1962.
11. A study of the number and kinds of species found in rivers in Eastern United States. R. Patrick. Proc. Acad. Natural Sciences of Philadelphia 113:215-258. 1961.
12. Algae in rivers of the United States. C. M. Palmer. In Algae & Metropolitan Wastes. Trans. 1960 Seminar. R. A. Taft San. Eng. Ctr., Cincinnati, Ohio. Tech. Rept. W61-3:34-38. 1961.
13. National Water Quality Network, Annual Compilation of Data. Public Health Service Publication No. 663, Editions: 1958, plus Supplement; 1959, 1960, plus Supplement 2, 1961, 1962, 1963 (Water Pollution Surveillance System).
14. Principal diatoms of major waterways of the United States. L. G. Williams and C. Scott. Limnology and Oceanography 7:365-379. 1962.

TABLE 4. COMMON ALGAE, EXCEPT DIATOMS, OF STREAMS

Blue-green algae	Green algae	Pigmented flagellates
Agmenellum (Merismopedia)	Actinastrum	Chlamydomonas
Anabaena	Ankistrodesmus	Chromulina
Anacystis (Microcystis)	Chlorella	Chrysococcus
Aphanizomenon	Chlorococcum	Glenodinium
Oscillatoria	Chodatella	Gymnodinium
Phormidium	Cladophora	Lepocinclis
	Closterium	Phacotus
	Coelastrum	Phacus
	Crucigenia	Trachelomonas
	Dictyosphaerium	
	Golenkinia	
	Micractinium	
	Oocystis	
	Pediastrum	
	Scenedesmus	
	Staurastrum	

CHAPTER V

PLANKTON ALGAE IN LAKES AND RESERVOIRS

The water requirements of growing cities and industry place increasing demands on surface water supplies. Already the majority of the larger communities are forced to rely primarily on surface rather than groundwater. More and more attention must therefore be given to both pollution control and treatment of the water particularly as supplies from less desirable sources have to be tapped (1).

Reservoirs, lakes, and ponds are all normally capable of supporting large, mixed groups of aquatic plants and animals. Algae of many kinds are included in this population. In lakes and reservoirs the common forms would be those found especially at or near the surface of the water where light is present in sufficient intensity to permit the algae to carry on their essential process of photosynthesis. The planktonic algae are capable of growing and multiplying while dispersed in the water and unattached to solid objects (2). Many other algae may be carried away from the shore line and from shallow ponds to become mixed with the true planktonic forms or to collect as mats of growth on the surface. Some species of algae are able to develop in abundance at depths of 10, 20, or more ft below the surface.

Studies indicate that there are many very minute algae and related organisms present in the water and that these may often exceed in volume the larger microscopic forms. These very minute forms are called nannoplankton, and the smallest forms are generally missed in the routine plankton analysis of water, in which only a low magnification with the compound microscope is used (3). The possible importance of these very small forms has not yet been given much consideration.

The larger, unattached algae constitute the bulk of the plankton counts made at many water treatment plants. As long as the total count remains low and no taste-and-odor algae or filter-clogging forms are present in conspicuous numbers, the waterworks engineer assumes that he is unlikely to have serious difficulties with the algae. A reasonable number of various kinds of common plankton organisms indicates a balanced biological condition in his raw water supply, implying that it will respond to water works treatment with the minimum of trouble. If one group, such as the blue-greens or the diatoms, or one particular species, such as *Anacystis cyanea* (formerly called *Microcystis aeruginosa)* or *Dinobryon divergens*, begins to predominate, then he becomes alert for possible trouble and can treat for the control of these algae before undesirable conditions become serious. When blue-green algae become predominant, it frequently indicates either that the water has been enriched with organic matter or that previously there has been a superabundance of diatoms. An understanding of relationships of this sort helps in instituting measures to prevent troublesome growths from developing (4).

In waters poor in nutrients, the factors limiting the number of algae may be the amounts of food materials available, particularly nitrates, phosphates, and, for diatoms, silicates. Some localities are proposing to restrict algal growths in the raw water supply by precipitating the phosphates as ferric phosphate. In one of the western cities a problem developed when 20 percent of a groundwater containing approximately 5 to 10 mg/l nitrogen as nitrate was mixed with a relatively infertile surface supply, causing heavy growths of the green algae, *Golenkinia*, *Palmella*, and *Scenedesmus*. In England the addition of groundwater to a reservoir caused a copious growth of the yellow-green alga, *Tribonema*. The growths of algae in some localities have been so rank as to necessitate withdrawing the reservoir from service. Many bodies of water are sufficiently rich in the essential nutrients that these nutrients do not become limiting factors in determining the abundance of algae. Other factors such as turbidity, water temperature, and parasitism may be the critical ones. Although it is assumed that the chemical and physical environment largely determines the amount of algal production, the exact relationships remain in many respects obscure.

BLOOMS

A number of the surface water algae have the ability to accumulate at times in such numbers as to form loose, visible aggregations called blooms which may cover very large areas of lakes and reservoirs or even streams. Blue-green algae may form these water blooms particularly during periods of warm, calm weather, when the algae which were previously distributed through the water rise to the surface. Other blooms may be associated with a rapid reproduction of a particular alga. Some water blooms have resulted in fish kills by interfering with reaeration, by excluding light necessary for photosynthesis in the lower areas and thereby preventing release of oxygen into the water, or by depleting the oxygen through decay or respiration within the bloom. Some water blooms release substances extremely toxic to fish, domestic animals, and birds, and extensive kills have resulted in several areas (5).

A considerable number of species of algae are capable of producing blooms. Some of the genera most frequently involved are the blue-green algae, *Anacystis (Microcystis)*, *Anabaena, Aphanizomenon,* and *Oscillatoria;* the green algae, *Hydrodictyon, Chlorella,* and *Ankistrodesmus* (fig. 35); the diatoms, *Synedra* and *Cyclotella;* and the flagellates, *Synura, Euglena,* and *Chlamydomonas.* Blooms of blue-green algae are particularly obnoxious. Blooms of flagellates and green algae are often encouraged by the addition of fertilizer in farm hatchery ponds in order to increase fish production (6).

Related to the blooms are the mats or blankets of filamentous green algae such as *Spirogyra, Zygnema, Oedogonium,* and *Cladophora* which at times may cover large areas of a reservoir or lake (7). Certain blue-green algae such as *Gloeotrichia natans* (fig. 36) may also form extensive floating masses. These growths cause an unsightly appearance in a community's water supply and serve as breeding places for gnats and midge flies. They may clog intake screens, cause tastes and odors, and interfere with the functioning of multiple-purpose reservoirs by collecting as debris on the shores and interfering with fishing and bathing. Many of the mat-forming algae are resistant to effective treatment with copper sulfate. Frequent inspections of raw water supplies for detection of the visible growths, together with routine microscopic analysis of water samples are necessary if the various kinds of algae are to be effectively controlled.

The list of the more common surface water algae is given in table 5. It is more extensive than for the other groups and includes a total of 68 species. Twenty-two plankton and other surface water algae are illustrated in color on plate I. Many of the species on the other lists in this manual could also be considered as prominent members of the flora of surface waters. Additional species would also need to be included to make the list fairly representative for any particular locality. Since the total number of known species of algae is many thousands, it is obviously not possible to include here all of even the common forms. Transeau (8) lists, for example, 275 species of the genus *Spirogyra,* Hustedt (9) describes more than 125 species belonging to the genus *Navicula,* and Gojdics (10) recognizes 155 species of *Euglena.*

It is emphasized that not all of the algae in the list of surface water forms are planktonic. The list includes algae which may originally be benthic (attached and bottom-dwelling) forms but are frequently swept away into the open water.

The open water algae have several mechanisms which aid in keeping them dispersed in the water and retard any tendency toward settling out. The pigmented flagellates, represented on plate I by *Euglena, Phacus, Gonium,* and *Eudornia,* are swimming forms with whip-like flagella which apparently aid in the forward movement of the cells through the water. Spines or the spine-like shapes of entire cells help to keep certain nonswimming green algae such as *Actinastrum, Micractinium,* and *Scenedesmus* suspended in the water. The large flat surfaces exposed to the water do the same thing for the diatoms, *Fragilaria* and *Tabellaria,* and the green alga, *Pediastrum.* A number of planktonic blue-green algae have internal gas vacuoles which help to keep the cells afloat.

Varieties are found among the surface water algae. Spherical or subspherical colonies of cells are found in *Coelastrum, Oocystis, Gomphosphaeria,* and *Sphaerocystis.* Filamentous forms include *Nodularia, Mougeotia, Zygnema, Cylindrospermum, Melosira,* and *Desmidium.* The diatoms *Stauroneia* and *Navicula* are boat-shaped and capable of moving through the water. The odd-colored *Botryococcus* with its green cells embedded in a brownish mucilaginous sheath is often irregular in form and surface.

From their specialization in shape and internal structure, many of the algae can be recognized readily under the microscope (fig. 37). This makes possible, in the routine microscopic analysis of water samples, a record of the presence and abundance of many of the significant genera or species. Several helpful books have been published giving lists, keys, descriptions, and illustrations of the algal flora of particular states or regions. Examples of these are the algae of Illinois (11), algae of Tennessee (12), algae of the western Great Lakes area (13), and the algae of the United States (14). Available information of this character will facilitate the accurate recording of the algae found in lakes and reservoirs which are being used as the water supply for an ever-increasing number of cities, towns, and industrial establishments.

Each year a seasonal cycle is evident in the plankton population of lakes and reservoirs. Diatoms generally increase in number in late winter, often with two or three additional pulses ocurring during the spring months. In early summer the green algae are likely to be abundant, followed in the late summer and early autumn by an increased growth of blue-greens. Then there will follow a late autumn maximum of diatoms. Throughout most of the winter the diatoms and certain other algae remain in the water but with little or no increase in numbers until conditions in the late winter stimulate the organisms to begin the cycle all over again. Various brown and green flagellates and the yellow-green alga *Tribonema* occasionally appear in the cycle as abundant growth for brief periods, the time of year depending in part upon the particular species involved.

When records of the phytoplankton present in a reservoir or lake are kept for a long period of time, they often reveal that certain genera and species are predominant year after year. In one metropolitan district (15) the reservoirs contained enormous numbers of *Tabellaria* and *Ceratium* with an abundance also of *Asterionella, Fragilaria, Synedra, Cyclotella, Dinobryon,* and *Pandorina.* Over a period of approximately 40 years, however, there was a gradual change in the predominant algae. *Tabellaria* dropped out completely and new forms appeared, chiefly *Stephanodiscus astraea* and *Stephanodiscus hantzchii,* together with several filamentous blue-green algae.

Diatoms found in large numbers in the Great Lakes and also in all major rivers of the United States are *Diatoma*

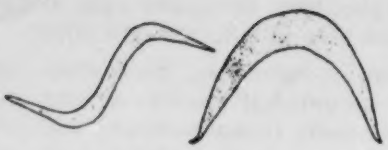


Figure 35.—*Ankistrodesmus falcatus.*

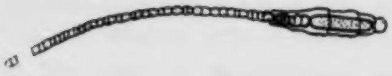


Figure 36.—*Gloeotrichia natans.*

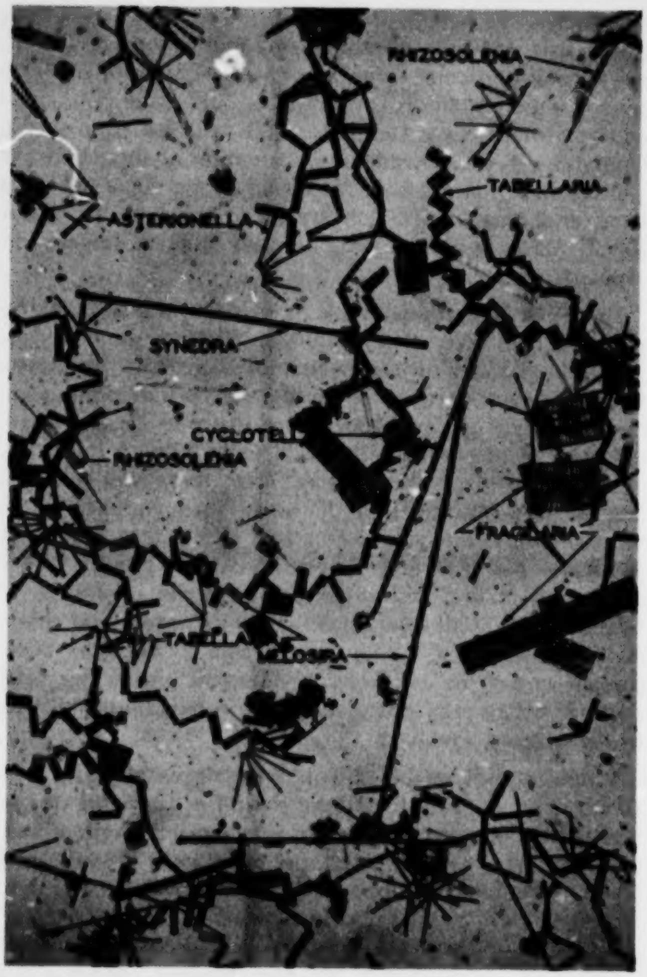


Figure 37. —Plankton diatoms, showing distinctive shapes of cells and colonies. The relative sizes of the various organisms are also evident in this composite photomicrograph which was furnished by J. R. Baylis, Engineering of Water Purification, Department of Water and Sewers, Bureau of Water, Chicago, Ill.

vulgare, Fragilaria crotonensis, Melosira ambigua, Melosira granulata, and *Stephanodiscus hantzschii.* Diatoms characteristic of the Great Lakes but absent or extremely rare in rivers of the United States are *Cyclotella comta, Cyclotella kutzingiana, Melosira binderana, Melosira islandica,* and *Rhizosolenia eriense* (16).

Although many environmental factors are relatively constant for any body of water and tend to keep the phytoplankton population stable, other factors will change sufficiently to influence the growth and relative abundance of the various genera and species comprising the flora.

REFERENCES

1. Ecology of significant organisms in surface water supplies. C. M. Tarzwell and C. M. Palmer. Jour. Amer. Water Wks. Assn. 43:568-578. 1951.
2. Some relationships of phytoplankton to limnology and aquatic biology. G. W. Prescott. In Problems of Lake Biology by F. R. Moulton. Amer. Assn. for Advancement of Sci., Science Press, Lancaster, Pa., p. 65-78. 1939.
3. A new counting slide for nannoplankton. C. M. Palmer and T. E. Maloney. Amer. Soc. Limnol. and Oceanog., Special Publ. No. 21, 6 p. March 1954.
4. The importance of algae to waterworks engineers. J.W.C. Lund. Jour. Inst. Water Engrs. 8:497-504. 1954.
5. Toxic fresh-water algae. W. M. Ingram and G. W. Prescott. Amer. Midland Naturalist 52:75-87. 1954.
6. Manganese for increased production of water-bloom algae in ponds. C. Henderson. Progressive Fish-Culturist 11:157-159. 1949.
7. The population of the blanket-algae of fresh-water pools. Emilie L. Platt. Amer. Naturalist 49:752-762. 1915.
8. The Zygnemataceae (fresh-water conjugate algae) with keys for the identification of genera and species. E. N. Transeau. Ohio State Univ. Press, Columbus, Ohio, 327 p. 1951.
9. Bacillariophyta (Diatomeae). F. Hustedt. Heft 10 in Die Süsswasser-Flora Mitteleuropas, by A. Pascher. Gustav Fisher, Jena, Germany, 466 p. 1930.
10. The genus Euglena. Mary Gojdics. Univ. Wisconsin Press, Madison, Wis., 268 p. 1953.
11. The algae of Illinois. L. H. Tiffany and M. E. Britton. Univ. Chicago Press, Chicago, Ill., 407 p. 1952.
12. Handbook of algae with special reference to Tennessee and the southeastern United States. H. S. Forest. Univ. Tennessee Press, Knoxville, Tenn., 467 p. 1954.
13. Algae of the western Great Lakes area, exclusive of desmids and diatoms. G. W. Prescott. Cranbrook Inst. Sci., Bloomfield Hills, Mich., Bull. No. 31, 946 p. 1951.
14. The fresh-water algae of the United States. Ed. 2. G. M. Smith. McGraw-Hill, N.Y., 719 p. 1950.
15. The reservoirs of the Metropolitan Water Board and their influence upon the character of the stored water. E. W. Taylor. Proc. International Assn. Theoretical and Appl. Limnol. 12:48-65. 1955.
16. Plankton population dynamics. L. G. Williams. U.S. Public Health Service Publication No. 663 — Supplement 2, 90 p. 1963.

TABLE 5. PLANKTON AND OTHER SURFACE WATER ALGAE

Group and algae	Plate or figure
Blue-Green Algae (Myxophyceae):	
Anabaena flos-aquae	VIII
Anacystis cyanea	VII
Anancystis thermalis	
Cylindrospermum stagnale	I
Gloetrichia natans	Fig. 36
Gomphosphaeria aponina	I

Group and algae	Plate or figure
Gomphosphaeria lacustris, collinsii type	
Gomphosphaeria wichurae	
Lyngbya versicolor	
Nodularia spumigena	I
Nostoc carneum	
Oscillatoria agardhii	
Phormidium retzii	
Plectonema tomasiniana	
Scytonema tolypothricoides	
Spirulina nordstedtii	
Filamentous Green Algae (of Chlorophyceae and Chrysophyceae):	
Cladophora fracta	
Desmidium gravellei	I
Hyalotheca mucosa	
Mougeotia genuflexa	
Mougeotia scalaris	I
Oedogonium iodiandrosporum	
Spirogyra fulviatilis	
Spirogyra varians	
Stigeocolonium stagnatile	
Tribonema minus	
Ulothrix tenerrima	
Vaucheria terrestris	
Zygnema pectinatum	
Zygnema sterile	I
Nonfilamentous, Non-Motile Green Algae (of Chlorophyceae):	
Actinastrum gracillimum	I
Actinastrum hantzschii	
Ankistrodesmus falcatus	Fig. 34, VI
Botryococcus braunii	I
Chlorella ellipsoidea	
Closterium aciculare	
Coelastrum microporum	I
Cosmarium botrytis	
Crucigenia quadrata	
Dictyosphaerium pulchellum	
Dimorphococcus lunatus	
Euastrum oblongum	I
Golenkinia radiata	VI
Kirchneriella lunaris	
Micractinium pusillum	I
Oocystis borgei	I
Oocystis lacustris	
Ophiocytium capitatum	
Pediastrum boryanum	I
Pediastrum duplex	Fig. 68
Scenedesmus bijuga	
Scenedesmus dimorphus	VI
Scenedesmus quadricauda	I
Schroederia setigera	
Selenastrum gracile	
Sphaerocystis schroeteri	I
Staurastrum polymorphum	
Tetraedrom limneticum	
Diatoms (Bacillariophyceae):	
Asterionella formosa	VIII
Cyclotella bodanica	III
Cyclotella kutzingiana	
Cyclotella meneghiniana	VIII
Cymbella turgida	
Diatoma vulgare	VIII
Eunotia lunaris	
Fragilaria construens	
Fragilaria crotonensis	VIII
Fragilaria pinnata	
Melosira ambigua	
Melosira binderana	
Melosira granulata	VIII
Melosira islandica	
Nitzschia acicularis	
Rhizosolenia eriense	
Synedra nana	
Synedra ulna	VII
Tabellaria fenestrata	VII
Tabellaria flocculosa	VIII

CHAPTER VI

ATTACHED ALGAE

Many of the algae which grow attached to some substrate are large and conspicuous, often covering a considerable area and extending several inches or even a few feet into the water. Those of importance in water supplies may grow not only in the stream, lake, and reservoir, but in the treatment plant itself. These algae are commonly found attached to such objects as the wet concrete walls of settling basins, the screens at the ends of the intake pipes, and the wood, brick, stone riprap, or even soil surfaces of reservoir walls and bottoms. Many are abundant in streams where they may be attached to submerged twigs or rock and other materials forming the stream bed. They are present in irrigation canals on the sides and bottom and on the gates and screens. They form dense growths in recreational lakes and in fish raising ponds, causing serious problems.

In small amounts these algae are not a cause for alarm, but when abundant they may become a decided nuisance. They may clog screens to which they are attached and reduce the flow in canals by the amount of space they occupy and the increased friction of their surfaces. In multiple-purpose lakes and reservoirs, they often interfere with swimming and fishing or develop such rank growths in the shallow margins that they are the cause of constant complaints from nearby residents. In addition, they may break away from their attachments to form unsightly surface mats, clog screens and filters, or produce offensive odors in the air and water. Other smaller algal forms may produce a continuous slimy and slippery layer on concrete or other surfaces, which in swimming pools is undesirable or even dangerous.

In Louisiana and other states just north of the Gulf of Mexico, *Pithophora* often becomes the predominant growth in fish ponds during the summer. It interferes with high fish production by reducing the growth of phytoplankton required directly or indirectly as fish food. The *Pithophora* also interferes with the harvesting of fish by forming a heavy growth on the pond. The growth can also promote overpopulation of bluegills by interfering with bass predation (1).

The attached algae considered here number 42 species, listed under their respective groups in table 6; 22 are illustrated in color on plate II. Included are diatoms, blue-green, green, and fresh-water red algae, but no flagellates. Many of these algae grow in the form of unbranched or branched filaments or tubes and are fastened at one end to the substrate by means of a special anchoring device. *Vaucheria* is a branched, tubular form with several common species (figs. 38, 39). Typical branching filamentous green algae are *Cladophora, Pithophora* (fig. 40), *Chaetophora, Stigeoclonium, Draparnaldia, Bulbochaete, Chara,* and *Nitella.* The species *Cladophora glomerata* is a very common attached alga in rapidly flowing water and is considered the most abundant filamentous alga in streams throughout the world (2). Nonbranching filamentous green algae include *Oedogonium, Microspora,* and *Ulothrix* and the more complex *Schizomeris* (fig. 41). The genera, *Audouinella* (formerly called *Chantransia), Batrachospermum,* and *Compsopogon* are fresh-water red algae, the last one being common in the southern states. Some filamentous blue-green algae such as *Phormidium, Lyngbya, Tolypothrix,* and *Stigonema* (fig. 42) form dense mats, one side of which is exposed and the other side attached to the substrate.

Some diatoms, such as *Achnanthes, Gomphonema,* and *Cymbella* are attached to surfaces by gelatinous stalks or tubes. In Australia, *Gomphonema* developed as an extensive growth and formed a slippery, felt-like mat covering the cement walls of an aqueduct for several miles (3). The species of *Cymbella* which grows inside a hollow tube, as illustrated on plate II, has sometimes been placed in a separate genus, *Encyonema* (4).

A white marble surface serving as the floor of an observation well in one water treatment plant became overgrown with a continuous brown layer of *Achnanthes.* The observation well was located on a conduit carrying water from sand filters to the clear well. The marble surface was brushed clean but the color returned within 2 weeks. After a second cleaning, electric lights that had been left on continuously at the bottom of the observation well were turned off, except for brief times when needed for display. The brown color did not return because the diatoms were not capable of developing in darkness.

The green alga, *Phytoconis* (formerly called *Protococcus)* is common as a thin green layer on the surface of moist wood and bark above the water line, but it is seldom found submerged. Another green alga, *Tetraspora* (fig. 43), is composed of minute, rounded cells in a soft, fragile, mucilaginous, common tube which is attached at one end to the substrate. It is one of the first algae to develop in abundance in the cold water of streams and pools after the ice melts in early spring. One of the most common blue-green algae attached to stones is *Calothrix* (fig. 44).

In reservoirs and lakes having rocky rather than sandy shores, *Cladophora* and other large filamentous algae often develop during the summer as extensive, massive

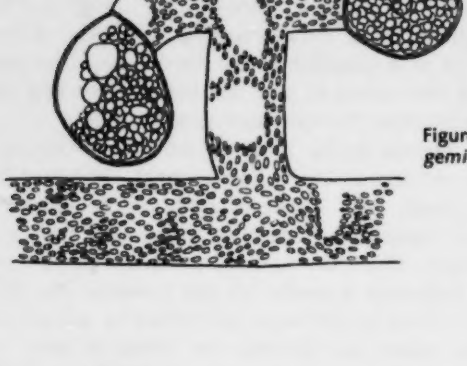


Figure 38.—*Vaucheria geminata.*

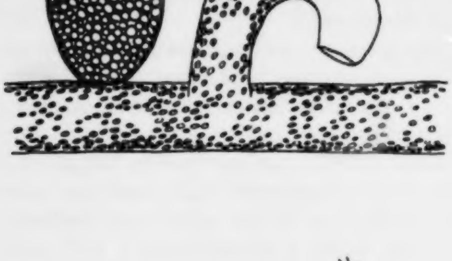


Figure 39.—*Vaucheria sessilis.*

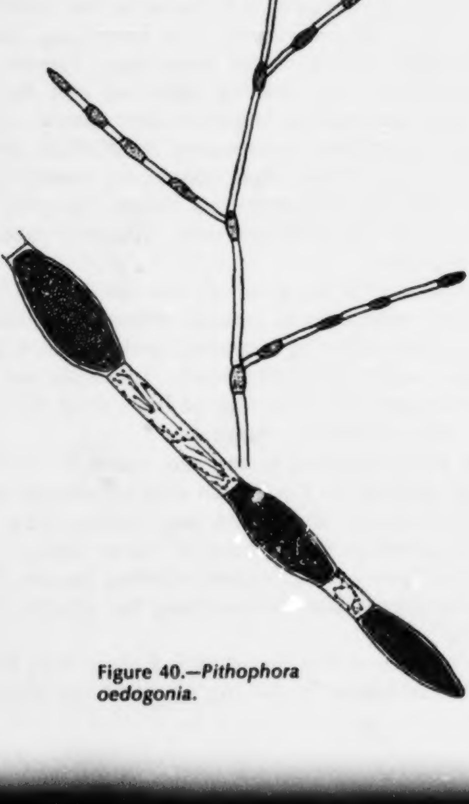


Figure 40.—*Pithophora oedogonia.*

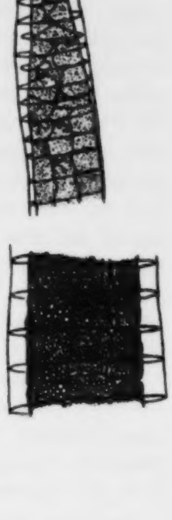


Figure 41.—*Schizomeris leibleinii.*

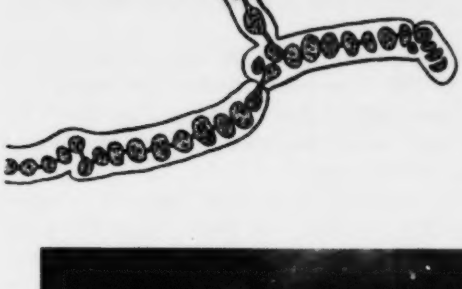


Figure 42.—*Stigonema hormoides.*

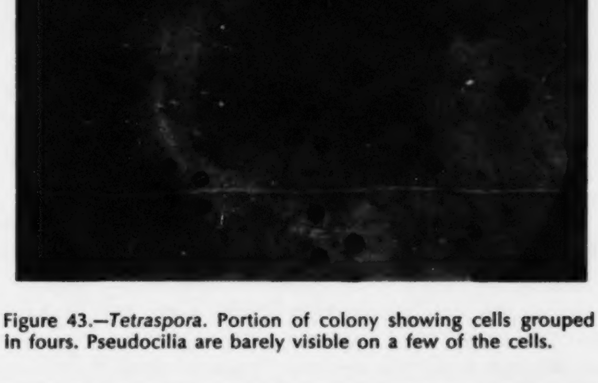


Figure 43.—*Tetraspora.* Portion of colony showing cells grouped in fours. Pseudocilia are barely visible on a few of the cells.

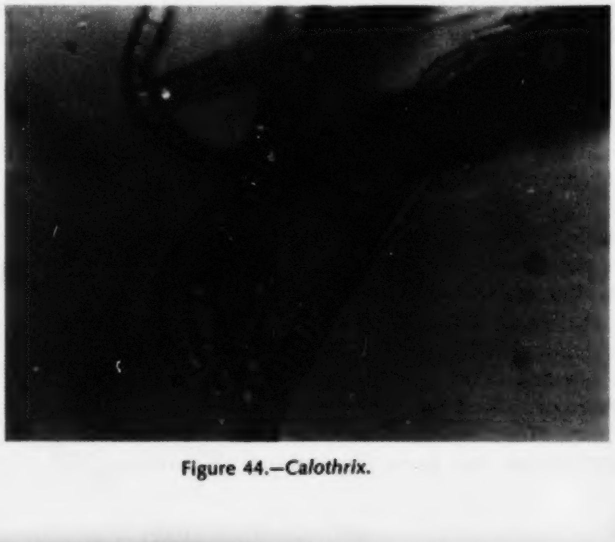


Figure 44.—*Calothrix.*

growths. When this material becomes detached and is thrown up on the shore, it may require immediate removal to prevent the development of septic odors (5).

In Lake Erie *Cladophora* has caused concern for many years, with indications that its growth is expanding and increasing in amount. One species, *Cladophora glomerata* is found growing on rock bottoms and sides down to almost 7 ft in depth. When the first crop matures in July the filaments become free floating as a result of maturation and of wave action. They are then frequently thrown up on shore by suitable winds and currents. Its mass interferes with the area as a bathing beach, and if not disposed of, the alga disintegrates and produces a strong odor of decomposition. A second crop may develop and mature in the fall but is generally less extensive and too late in the year to interfere with the use of bathing beaches (6).

One species, *Cladophora profunda* var. *nordstedtiana* has been found at 150 ft or more below the surface of Lake Ontario. Increasingly it has become a problem for fishermen using nets, since the nets become entangled with the filaments of the alga.

Nuisance growths of *Cladophora* often occur in streams or along the shoreline of lakes in the vicinity of sewer outfalls. Large concentrations of wastes and certain metallic ions can be toxic to *Cladophora*, and it may be replaced by *Stigeoclonium*, *Phormidium*, and other algae that are more tolerant to these materials (7). The eutrophication of Lake Erie and Lake Ontario is certainly directly associated with the increased growth of *Cladophora* in these lakes.

Drastic measures often have to be taken to control the attached algae, especially if the growths are neglected until large quantities threaten to cause trouble. One city adapted a floor-cleaning machine, fitted with a cylindrical wire brush, for use in scraping the agal growth from the concrete floor of a 13-mil-gal reservoir. The machine proved to be much more effective than hand scrapers in removing the attached portions of the algae from the more than 100,000 sq ft of concrete. The detached algae were then flushed from the reservoir floor by streams of water from a fire hose (7). The use of chemicals to kill attached algae when they are present in quantity may not solve the problem, because dead algae as well as living ones can clog filters and screens, release slimes into water, and cause tastes and odors.

In areas in the western part of the country where there are extensive systems of canals for irrigation farming, massive growths of attached algae, together with certain aquatic flowering plants, constitute a serious problem. Because of their bulk, they impede the flow of water through the ditches and clog the control gates and the distribution lines. Their large volume decreases the capacity of the irrigation ditch, causing the water to overflow. In California one canal overflowed while carrying only 25 percent of its rated capacity due to a heavy growth of *Cladophora*. Near San Francisco the most troublesome alga in open canals has been *Cladophora*. It produces long filaments and mats on the sides and bottom (8). *Cladophora* and *Rhizoclonium* are by far the most important algae encountered. The peak of their development is generally in the spring after which they often become inconspicuous during the summer with new growth beginning in the autumn. The green alga *Enteromorpha* (fig. 45), commonly thought of as a brackish water form, may become abundant during the summer, and the fresh-water red alga, *Compsopogon*, may flourish during September.

The red alga *Thorea* forms long skeins of unbranched filaments, some as long as 20 ft, and is most abundant in October. The green alga *Dichotomosiphon* is another filamentous form especially evident in the spring and fall, while *Oedogonium* (fig. 46), *Spirogyra*, and *Oscillatoria princeps* form abundant growths in the summer (9, 10). The algae which occur in sufficient quantities to affect the operation of the canals and ditches are listed in table 7. One common method of control has been the mechanical removal of the algae by means of chains or scrapers that are pulled along the canals by tractors. Four irrigation districts in Arizona spend a total of approximately $250,000 annually to control this growth.

Attached algae are present and apparently significant in the trickling filters of sewage treatment plants. They form a large part of the population of microorganisms growing in a layer around the stones of the filter. The exposed surface of the layer is predominantly fungal, the intermediate portion is predominantly algal, and the basal portion against the stone is a fungal, algal, and bacterial mixture. The layer may reach a thickness of 1 to 2 mm. The attached alga most frequently encountered is *Stigeoclonium* (fig. 47). In addition to its branching filaments it also develops as a basal, attached, irregular, tight mat of cells which strongly resembles a colony of the nonfilamentous green alga *Chlorococcum*. The branching filaments of *Stigeoclonium* rise from this basal mat. Species of attached algae from the trickling filters of one treatment plant (6) were reported as *Stigeoclonium nanum, Ulothrix tenuissima, Phormidium uncinatum, Amphithrix janthina,* and *Characium* sp. Other algae commonly mixed with the attached forms were *Scenedesmus bijuga, Oocystis parva, Chlorella vulgaris, Chlamydomonas, Nitzschia palea,* and *Anacystis montana*.

Consideration is being given to the use of attached algae in tertiary treatment of sewage effluents. In addition, the algal growth might be harvested and prepared for use as fertilizer, mulch, or cattle feed. The attached forms would not present the difficulty of harvesting that is encountered with plankton organisms.

In some areas adjacent to the sea, cattle have become adjusted to feeding on the brown alga known as kelp. A few reports indicate that cows and horses have eaten fresh-water attached *Cladophora* or other bottom algae. Even squirrels have been observed nibbling tender growths of *Cladophora* from the stones along the shores of lakes (11).

Thus, it is evident that the attached algae may produce undesirable conditions or be put to good use depending

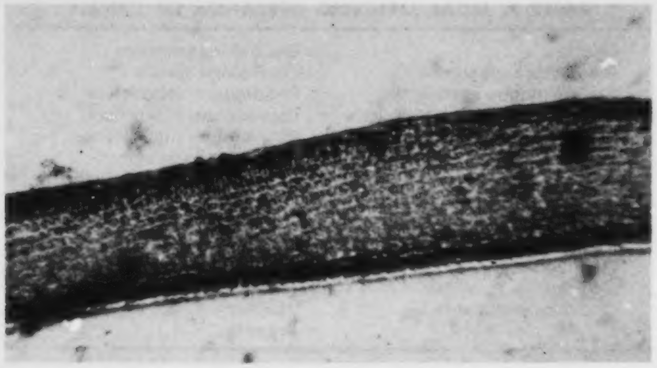


Figure 45.—*Enteromorpha*.

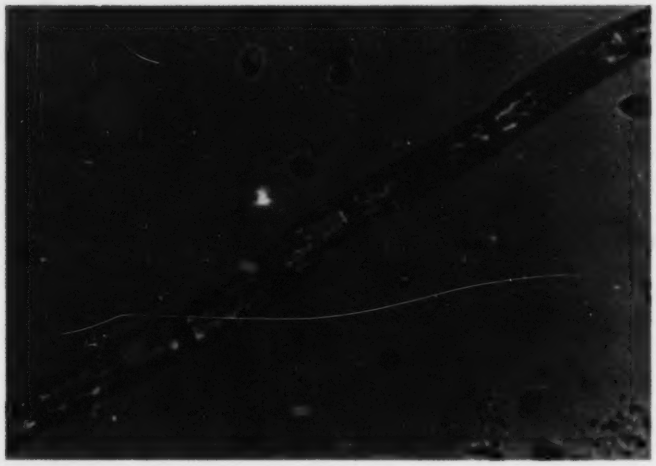


Figure 46.—*Oedogonium*.

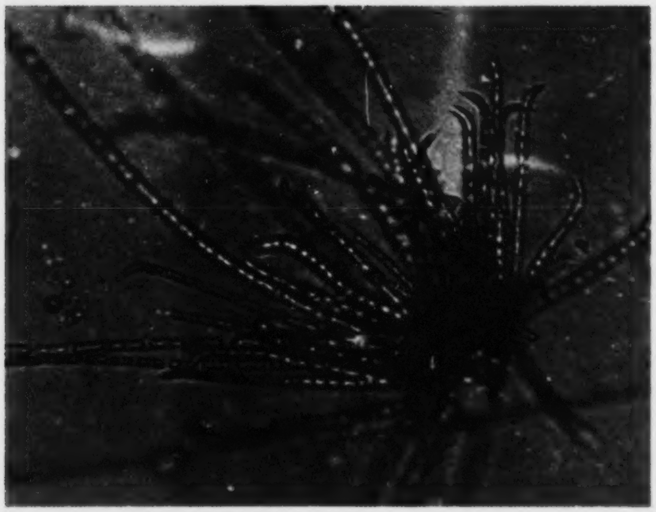


Figure 47.—*Stigeoclonium* (immature).

upon the particular locations and conditions in which they develop.

REFERENCES

1. Control of a branched alga, *Pithophora*, in farm fishponds. J. M. Lawrence. Progressive Fish Culturist 16:83-86. 1954.
2. The ecology of river algae. J. L. Blum. Bot. Rev. 22:291-341. 1956.
3. The effects of algae in water supplies. D. H. Matheson. International Water Supply Assn., General Rept. to 2d Congress. Paris, France, 82 p. 1952.
4. Fresh-water biology. H. B. Ward and G. C. Whipple. J. Wiley and Sons, N.Y., 1110 p. 1945.
5. Algal nuisances in surface waters. N. J. Howard and A. E. Berry. Canadian Jour. Public Health 24:377-384. 1933.
6. *Cladophora* investigations, 1959. A report of observations on the nature and control of excessive growth of *Cladophora* sp. in Lake Ontario. Ontario Water Resources Commission, 30 p. 1959.
7. Environmental needs of nuisance organisms. C. M. Palmer. Proc. 4th Ann. Water Quality Res. Symp., N.Y. State Dept. Health, Albany, N.Y., p. 8-35. 1967.
8. Weed growths in reservoirs and open canals. C. E. Arnold. Jour. Amer. Water Wks. Assn. 27:1684-1693. 1935.
9. The study of the algae of irrigation waters. Janet D. Wien. Arizona State College, Tempe, Arizona. 37 p. (Mimeographed). Mar. 31, 1958.
10. Continuous sampling of trickling filter populations. II. Populations. W. B. Cooke and A. Hirsch. Sewage and Indust. Wastes 30:138-156. 1958.
11. Some economic aspects of the algae. L. S. Tiffany. School Sci. and Math. 28:583-593. 1928.

TABLE 6. ATTACHED ALGAE

Group and algae	Plate or figure
Blue-Green Algae (Myxophyceae):	
Calothrix braunii	
Lyngbya lagerheimii	II
Lyngbya ocracea	
Nostoc pruniforme	
Oscillatoria tenuis	30
Phormidium retzii	
Phormidium uncinatum	II
Stigonema minutum	
Tolypothrix tenuis	II
Green Algae (Nonmotile Chlorophyceae, Charophyceae):	
Bulbochaete insignis	II
Chaetophora attenuata	
Chaetophora elegans	II
Chara globularis	II
Cladophora crispata	II
Cladophora glomerata	4
Draparnaldia glomerata	II
Gloeocystis gigas	
Microspora amoena	II
Nitella flexilis	
Oedogonium boscii	
Oedogonium grande	
Oedogonium suecicum	II
Palmella mucosa	II
Phytoconis botryoides	II
Pithophora oedogonia	40
Rhizoclonium hieroglyphicum	III
Schizomeris leibleinii	41
Stigeoclonium lubricum	II
Tetraspora gelatinosa	II
Ulothrix zonata	II
Vaucheria geminata	38
Vaucheria sessilis	II

Group and algae	Plate or figure
Red Algae (Rhodophyceae):	
Audouinella violacea	II
Batrachospermum moniliforme	II
Compsopogon coeruleus	II
Diatoms (Bacillariophyceae):	
Achnanthes microcephala	II
Cocconeis pediculus	
Cymbella prostrata	II
Epithemia turgida	
Gomphonema geminatum	II
Gomphonema olivaceum	
Rhoicosphenia curvata	

TABLE 7. ALGAE AFFECTING OPERATION OF CANALS

Chara
Cladophora glomerata
Compsopogon coeruleus
Dichotomosiphon tuberosus
Enteromorpha intestinalis
Hydrodictyon reticulatum
Lyngbya aestuarii
Lyngbya putealis
Microspora wittrockii
Mougeotia
Oedogonium
Oscillatoria amphibia
Oscillatoria chalybea
Oscillatoria princeps
Oscillatoria tenuis
Phormidium inundatum
Phormidium subfuscum
Phormidium uncinatum
Prasiola nevadense
Rhizoclonium hieroglyphicum
Sirogonium
Spirogyra
Spirulina major
Stigeoclonium lubricum
Thorea ramosissima
Vaucheria
Zygnema

CHAPTER VII

ALGAE AND EUTROPHICATION

Eutrophication refers to the continuous enrichment of waters by the addition of substances that provide for the increasing growth of aquatic life. Commonly it is limited to non-flowing bodies of water such as lakes and reservoirs and not to rivers and smaller streams. The word pollution could be substituted for eutrophication, although the emphasis of the word pollution is upon the addition of substances to water which directly and indirectly interfere with the use of the water. The word pollution is commonly used in connection with flowing water and also with lakes and reservoirs, at least when the substances added do not stimulate increased growth of aquatic organisms. Thus a lake could be polluted with acids and sulfates and debris from mining operations and could be eutrophied with organic wastes from household sewage. With a river the word pollution would more often be used for both conditions (1).

Natural eutrophication tends to occur regularly but very slowly, often over a period of hundreds of years. Human activity is generally responsible for rapid eutrophication as household wastes, agricultural land drainage, and organic industrial wastes or their decomposition products reach the lakes and reservoirs.

Algae are invariably involved as representing part or most of the increased growth stimulated by eutrophication. The two substances considered most significant in this growth are nitrogenous compounds and phosphates. These, together with carbon dioxide, are generally the materials whose availability determines the quantity and quality of algal growth. A relatively pure body of water has a very limited amount of the essential nutrients. If all three of these are increased, many kinds of algae may be able to grow in large numbers. If one is increased much more than the others, only a selected few types of algae may be able to thrive. Many other elements and conditions are also required for increased growth of algae, but these are less often the critical factors determining the amount and quality of algal growth in a body of water with an established flora.

When gross eutrophication is reached, large, visible aggregations of floating algae bloom extensively, particularly blue-green forms which develop during the late summer. *Anacystis (Microcystis),* and *Anabaena* are the most common algae to bloom but others such as *Aphanizomenon, Gomphosphaeria, Rivularia,* and *Oscillatoria* may also produce blooms. Less often *Spirulina* or *Arthrospira* may be responsible. The blooms may cause unusually severe problems of tastes and odors, filter and screen clogging, and slime accumulation in pipes; some may be toxic, and all may cause fish kills when large numbers of the algae die at about the same time. In decomposition they utilize oxygen in the water, thus depriving the fish below of this essential element. Blooms also interfere in recreational lakes, with fishing, bathing, boating, and often reduce the beauty of the lake.

As eutrophication proceeds, the algae which tend to become prominent, in addition to the bloom-formers listed above, may be planktonic, floating, periphytic, or they may be larger forms attached to rocks and soil. Included would be *Cladophora, Gloeocystis, Mougeotia, Oedogonium, Spirogyra* (2), and the diatoms which are characteristic of and reach their best development in eutrophic waters (3). The significance of large growths of *Cladophora* in the eutrophied Lakes Erie and Ontario is referred to in the chapter on Attached Algae.

The quantity of phytoplankton that can develop in a eutrofied lake can be very large. For Lake Sebastecook, Maine, the net weight per surface area was calculated to be 530 lb/acre in February, 630 in May, 1,000 to 2,260 in August, and 570 in November. Phytoplankton counts ranged from 600/ml in February to 212,000/ml during a bloom in August. The amount of the algal mass varied from 15 to 560 ppm. In Lake Michigan, phytoplankton populations in the Chicago - Calumet area were dense. In 1962, counts up to 1,298 algae/ml were recorded, while in 1963, counts increased to a high of 2,143 (4).

In specific terms, a eutrophic lake has been characterized as one that is generally shallow and possesses an extensive littoral zone with plant growth. It is rich in basic nutrients with the average annual concentrations of the inorganic forms of nitrogen and phosphorus being somewhat greater than 0.300 mg/l and 0.015 mg/l, respectively. The alkalinity ranges from 50 to 100 mg/l and the water is moderately hard. Eutrophic lakes typically support large quantities of phytoplankton composed of comparatively few species; pulses and blooms are common and frequent during the growing season. In general the rate of gross primary production in eutrophic lakes ranges from 0.5 to 5.0 gm dry organic material/sq m/day during the most favorable growing season while the primary production of organic carbon is on the order of 480 metric tons/sq km/year (5).

Thus, Oneida Lake, New York, was considered in 1956 to meet the qualifications for a eutrophic lake from five different considerations as follows:

1. It is relatively shallow with a mean depth of 25 ft and possesses extensive shoal areas with plant growth, amounting to 23 percent of the lake's surface area.

2. The average concentration of nitrate nitrogen was 0.256 mg/l and of total phosphorus 0.190 mg/l. Ammonia nitrogen and organic nitrogen were additional sources of nitrogen. Alkalinity and hardness averaged 86 and 150 mg/l as $CaCO_3$, respectively.

3. The algal population for the summer months in 1956 was predominantly blue-green and green algae, whereas in 1927, it was predominantly a diatom population. The algal growth was moderate on the average, but there were frequent heavy blooms or pulses.

4. The rate of gross production was estimated to be about 2.6 gm of organic material/sq m/day.

5. The degree of productivity was estimated to be about 350 metric tons of organic carbon/sq km/year (5).

Oneida Lake produced blooms even before European settlement. In the eighteenth century, Indians called it "stinking green" (6). The most important contributors to eutrophication of the lake are now a barge canal and four creeks. They contribute substantially to the enrichment of the lake. Wastes from lakeside dwellings are also important in effecting the condition of local shore-lying areas. In 1961, 35 genera of algae were recorded as predominant in the lake. Included were 8 blue-greens, 3 flagellates, 13 greens (non-filamentous), 1 golden-brown, 4 filamentous greens and yellow-greens, and 6 diatoms. These are listed in Table 8 (5).

The Great Lakes are a large expanse of water, covering nearly 95,000 sq mi. Lake Superior is the second largest lake in the world and even the smallest, Lake Ontario, ranks fourteenth. Lakes Erie and Ontario and the southern part of Lake Michigan have already become eutrophic, and because of the increasing activities of the human population around all of the lakes, there has been a gradual increase in dissolved solids, including nitrogen and phosphorus, in all but Lake Superior. Over a 60-year period, Lakes Ontario and Erie had increases in dissolved solids of more than 30 percent, Lake Michigan 20 percent, and Lake Huron 10 percent.

Blooms of algae are frequent on Lakes Erie and Ontario and the bloom rhythm is getting faster and faster on parts of Lake Michigan (7).

Records of phytoplankton from a 12-month study in 1950-1951 from a total of 245 samples taken near the mouths of 10 rivers flowing into Lake Erie showed four classes and 30 genera of algae. The diatoms were the most common and green algae were second in abundance. Table 9 lists the genera of algae identified (8).

Reports of samples collected about 20 years before, 1928-1930, indicate a total at that time of 80 genera of phytoplankton in Lake Erie, including 12 blue-greens, 20 diatoms, 13 flagellates, and 35 greens and related forms (9,10). This drop from 80 genera to 30 genera in 20 years could be evidence of a rapid eutrophication of the lake during that period.

Prevention of further damage to the lake waters as well as improvement in the water quality can be attempted primarily by restricting the introduction of nutrients that result from human activities (1). Gradual flushing of the lakes by addition of rain water together with water flow should eventually reduce the amounts of nutrients present. Indications are now that the western end of Lake Erie is already beginning to improve. "The advent of trout and salmon in Lake Erie and the Detroit River, one of the most polluted links in the Great Lakes chain, is viewed by some observers as one of the many intriguing, sometimes dramatic signs that efforts to clean up the lakes are starting to take effect" (11).

REFERENCES

1. Eutrophication, Introduction, Summary, and Recommendation. G. A. Rohlich. In Eutrophication: Causes, Consequences, Correctives. Proc. Symposium, 1967. National Acad. Sci., Washington, D.C., 661 p. 1969.
2. Some effects of sewage effluent upon phyco-periphyton in Lake Murray, Oklahoma. H. E. Schlichting, Jr. and R. A. Gearheart. Proc. Okla. Acad. Sci. 46:19-24. 1966.
3. The diatoms of Linsley Pond. R. Patrick. Proc. Acad. Natural Sci. Philadelphia 95:53-110. 1943.
4. The practice of water pollution biology. K. M. MacKenthun. U.S. Dept. Interior, Fed. Water Pollution Control Admin., Div. of Technical Support, 281 p. 1969.
5. Chemical and microbiological aspects of Oneida Lake, New York. R. C. Mt. Pleasant, M. C. Rand, and N. L. Nemerow. New York State Dept. of Health, Research Rept. No. 8. 1961.
6. Eutrophication in North America. W. T. Edmondson. In Eutrophication: Causes, Consequences, Correctives. Proc. Symposium, 1967. National Acad. Sci., Washington, D.C., p. 124-149. 1969.
7. Superior-Michigan-Huron-Erie-Ontario. Is it too late? G. Young. National Geographic 144 (2):147-185. 1973.
8. Survey of the phytoplankton at the mouths of ten Ohio streams entering Lake Erie. C. R. Sullivan, Jr. In Lake Erie Pollution Survey, Final Report. Ohio Dept. Natural Resources, Div. of Water, p. 152-156. 1953.
9. The phytoplankton of western Lake Erie. L. H. Tiffany. In Limnological Survey of Western Lake Erie by S. Wright. U.S. Dept. of Interior, Fish and Wildlife Service, Special Scientific Rept. - Fisheries No. 139, p. 139-200. 1955.
10. A survey of the microplankton of Lake Erie. R. R. Burkholder. In Limnological Survey of Eastern and Central Lake Erie, 1928-1929. U.S. Dept. Interior, Fish and Wildlife Service. Special Scientific Rept. - Fisheries No. 334, Washington, D.C., p. 123-144. 1960.
11. Great Lakes pollution fight is gaining. W. K. Stevens. The New York Times for May 23, 1974. p. 1 and 42.

TABLE 8. PREDOMINANT ALGAE IN ONEIDA LAKE, 1961

- Blue-Green Algae
  - Agmenellum (Merismopedia)
  - Anabaena
  - Anacystis
    - (Chroococcus)
    - (Microcystis)
  - Calothrix
  - Coelosphaerium (Gomphosphaeria)
  - Lyngbya
  - Oscillatoria
  - Rivularia
- Diatoms
  - Asterionella
  - Fragilaria
  - Nitzschia
  - Stephanodiscus
  - Synedra
  - Tabellaria
- Flagellates
  - Ceratium
  - Euglena
  - Volvox
- Green (Non-Filamentous) Algae
  - Actinastrum
  - Ankistrodesmus
  - Chlorella
  - Closterium
  - Coelastrum
  - Hydrodictyon
  - Micrasterias
  - Oocystis
  - Pediastrum
  - Phytoconis (Protococcus)
  - Scenedesmus
  - Sphaerocystis
  - Staurastrum
- Green and Yellow-Green (Filamentous) Algae
  - Cladophora
  - Mougeotia
  - Tribonema
  - Ulothrix
- Golden-Brown Algae
  - Chrysidiastrum

TABLE 9. PHYTOPLANKTON IN LAKE ERIE, 1951 - 1952

- Blue-Green Algae
  - Agmenellum (Merismopedia)
  - Anabaena
  - Anacystis
    - (Chroococcus)
    - (Microcystis)
- Diatoms
  - Asterionella
  - Cyclotella
  - Diatoma (Odontidium)
  - Flagilaria
  - Gyrosigma
  - Melosira
  - Navicula
  - Nitzschia
  - Stephanodiscus
  - Surirella
  - Synedra
  - Tabellaria
- Flagellates
  - Ceratium
  - Glenodinium
  - Pandorina
- Green Algae
  - Closterium
  - Cosmarium
  - Gloeocystis
  - Hydrodictyon
  - Oocystis
  - Pediastrum
  - Scenedesmus
  - Spirogyra
  - Staurastrum
  - Ulothrix

CHAPTER VIII

CLEAN WATER ALGAE

Clean water organisms are those found in water which is free of sewage or other organic enrichment due to waste discharge. The clean water may be that portion of streams above sewage outlets or far enough downstream for the sewage to have been reduced to relatively inoffensive salts and other simple compounds. Most of these products of sewage decomposition are nutrients and will stimulate organisms such as algae to grow much more profusely than they do in the stream above the sewage outlet, where nutrients are limited in quantity. The kinds of algae in the clean waters upstream and downstream tend, however, to be similar.

Large numbers of algae are found in the section of the stream often called the recovery zone, which contains partially decomposed sewage. It is difficult to select particular algae as the best indicators of the downstream clean water zone, since it is adjacent to the recovery zone where purification is still in progress. As with the polluted water forms, it is more satisfactory to emphasize the presence or absence of several of the clean water algae rather than of any one species in defining the clean water zone.

Forty-six species have been selected as representative of the clean water algae and are listed in table 10. Twenty-two of these species are illustrated in color on plate III. The group includes several diatoms, several brown-to-reddish flagellates, certain greens and blue-greens, and a few fresh-water red algae of the class Rhodophyceae. A number of them, particularly the flagellates, are very minute and appear small even under the high power of a compound microscope, but they frequently are better indicators of clean water than many larger algae that may be mixed with them. However, a few of the larger forms are also useful in indicating the condition of the water and are represented by certain species of *Cladophora, Rhizoclonium, Lemanea*, and others.

Some of the clean water algae are planktonic, while others are attached to rocks or other material at the bottom or sides of the stream like *Calothrix parietina* (fig. 48). The blue-green algae *Entophysalis lemaniae* (formerly called *Chamaesiphon incrustans)* and the diatom *Cocconeis placentula* are epiphytic, i.e., they grow attached to the surface of other plants in the water. Several of the genera having clean water species include also other species whose reaction to sewage pollution is different from the clean water forms. Both the pollution and clean water groups are represented by contrasting species of *Navicula, Nitzschia, Phormidium, Agmenellum, Surirella, Ulothrix,* and *Euglena*. In these same genera, as well as in *Pinnularia, Cyclotella,* and *Cladophora*, there are also species considered to be indifferent to sewage. Identification as to species is, therefore, essential for any accurate differentiation of pollution zones through the use of algae as indicator organisms.

Clean water algae are listed by some writers as typical of the oligosaprobic zone, which is defined as the zone of cleaner water where mineralization has been completed. The water is often saturated or supersaturated with oxygen. It is clear and transparent, and the bottom is usually relatively free of sediment. Organic material containing nitrogen or phosphorus is small in amount. The water generally is cold and often deep. It is low in calcium, magnesium, iron, sulfates, and half-bound carbonates. The alkalinity should be less than 40 ppm and the pH below 7.4 (1). The water body has no shoals and little beach. Algae and higher green plants predominate, while molds and bacteria are present in only small numbers. Protozoa, rotifers, crustacea, small fish, and game fish are all present in moderate numbers. Almost all of the algae are attached forms and even these are few in number. The number of species present generally ranges from 1 to 7. At high elevations *Hydrurus* may be the only alga present. Spring water may contain minerals but commonly is very low in nitrates and phosphates (1). However, from the standpoint of sanitation this zone of water is not likely to be clean or pure, since it undoubtedly is not free of bacteria and viruses of intestinal origin. The oligosaprobic zone does not have a fixed location or length, since the distance required for stream purification varies according to temperature, the pollution load, the rate of flow, and other factors. The limited flora and fauna of springs and pure mountain streams are placed in a separate group known as katarobic (2). More extensive lists of organisms considered characteristic of the various pollution zones have been published recently by Butcher (3), Kolkwitz (4), Lackey (5), Liebmann (6), Patrick (7), and others.

Butcher (3) claimed that a community composed of the diatom *Cocconeis* and the blue-green alga *Entophysalis* (listed as *Chamaesiphon)* is present in the portion of the stream which has returned to normal following purification of a polluted condition. Kolkwitz (4) lists as oligosaprobic 61 diatoms, 42 green algae, 41 pigmented flagellates, 23 blue-green algae, and 5 red algae. Lackey (5) found 77 species of planktonic algae in the clean water portion of a small stream, 40 of which were absent in the polluted area a short distance downstream. Liebmann (6) emphasized particularly the following algae as characteristic

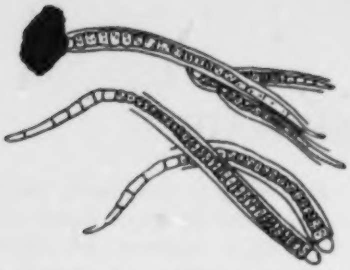


Figure 48.—*Calothrix parietina* is attached to logs and stones in running water.

of the oligosaprobic zone: The flagellate *Chromulina rosanoffi* in slow-flowing water, and the flagellate *Mallomonas caudata,* the green algae *Ulothrix zonata* and *Microspora amoena,* and the red algae *Lemanea annulata* and *Batrachospermum vagum* in rapidly flowing water. Patrick (7) listed *Amphora ovalis* and *Gyrosigma attenuatum* as examples of diatoms that seemed to be adversely affected by high organic content of water. Brinley (8) reported that the presence of the flagellate algae *Chrysococcus* and *Cryptomonas* in large numbers indicated that the decomposition of organic matter in the stream had been completed.

Some workers have emphasized the relationship of whole groups of algae to pollution in studies involving stream purification. Lackey (9) reported that two classes of algae, the olive green flagellates, or *Cryptophyceae,* and the yellow-green flagellates, or *Chrysophyceae,* appeared to be indicators of clean, unpolluted water. They tend to be present in moderate to great abundance in clean water and reacted adversely to pollution. In another study (5) he observed that all of the *Chrysophyceae* and most of the *Cryptophyceae, Volvocales,* and *Bacillarieae* (diatoms) which were present in clean water were killed in the zone of pollution. Patrick (10) stated that a healthy portion of a stream contained mostly diatoms and green algae. Rafter (11) and other earlier workers assumed that the absence of large amounts of blue-green algae was an indication of clean water.

It is apparent that the lists of clean water algae reported by various workers include a wide variety of forms belonging to various groups. Some are planktonic while others are epiphytic or attached to rocks and other material on the bottom of the stream.

REFERENCES

1. The algae: a review. G. W. Prescott. Houghton, Mifflin Co., 436 p. 1968.
2. The microscopy of drinking water. Ed. 4. G. C. Whipple, G. M. Fair, and M. C. Whipple. J. Wiley and Sons, N.Y., 586 p. With 19 color plates. 1948.
3. Pollution and repurification as indicated by the algae. R. W. Butcher. Fourth International Congress for Microbiology, held 1947. Rept. of Proc. 1949.
4. Oekologie der Saprobien. Uber die Bezeihungen der Wasserorganismen zur Umwelt. R. Kolkwitz. Schriftenreihe des Vereins für Wasser-, Boden-, und Lufthygiene. No. 4, 64 p. 1950.
5. Stream enrichment and microbiota. J. B. Lackey. Public Health Repts. 71:708-718. 1956.
6. Handbuch der Frischwasser-, und Abwasserbiologie. H. Liebmann. R. Oldenbourg, München, Germany, 539 p. 1951.
7. Factors effecting the distribution of diatoms. Ruth Patrick. Bot. Rev. 14:473-524. 1948.
8. Biological studies, Ohio River pollution survey. I. Biological zones in a polluted stream. F. G. Brinley. Sewage Wks. Jour. 14:147-159. 1942.
9. Two groups of flagellated algae serving as indicators of clean water. J. B. Lackey. Jour. Amer. Water Wks. Assn. 33:1099-1110. 1941.
10. A proposed biological measure of stream conditions. Ruth Patrick. Proc. 5th Indust. Waste Conf., Purdue Univ. Eng. Bull. 34:379-399. 1950.
11. The microscopical examination of potable water. G. W. Rafter. Van Nostrand Co., N.Y. 1900.

TABLE 10. CLEAN WATER ALGAE

Group and algae	Plate or figure
Blue-Green Algae (Myxophyceae):	III
Agmenellum quadriduplicatun glauca type	III
Calothrix parietina	III
Coccochloris stagnina	III
Entophysalis lemaniae	III
Microcoleus subtorulosus	III
Phormidium inundatum	
Green Algae (Nonmotile Chlorophyceae):	
Ankistrodesmus falcatus, var. acicularis	III
Bulbochaete mirabilis	
Chaetopeltis megalocystis	
Cladophora glomerata	III
Draparnaldia plumosa	
Euastrum oblongum	I
Micrasterias truncata	III
Rhizoclonium hieroglyphicum	III
Staurastrum punctulatum	III
Ulothrix aequalis	III
Vaucheria geminata	Fig. 39
Red Algae (Rhodophyceae):	
Batrachospermum vagum	
Hildenbrania rivularis	III
Lemanea annulata	III
Diatoms (Bacillariophyceae):	
Amphora ovalis	
Cocconeis placentula	
Cyclotella bodanica	III
Cymbella cesati	
Meridion circulare	III
Navicula exigua var. capitata	
Navicula gracilis	III
Nitzschia linearis	
Pinnularia nobilis	III
Pinnularia subcapitata	
Surirella splendida	III
Synedra acus var. angustissima	
Flagellates (Chrysophyceae, Cryptophyceae, Euglenophyceae, and Volvocales of Chlorophyceae):	
Chromulina rosanoffi	III
Chroomonas nordstetti	
Chroomonas setoniensis	
Chrysococcus major	
Chrysococcus ovalis	
Chrysococcus refescens	III
Dinobryon stipitatum	
Euglena ehrenberqii	
Euglena spirogyra	
Mallomonas caudata	VII
Phacotus lenticularis	III
Phacus longicauda	
Rhodomonas lacustris	III

CHAPTER IX

ALGAE AND POLLUTION—FRESH WATER

Water containing one or more of various types of impurities may be said to be polluted. The term *pollution*, however, is usually restricted to situations in which the condition is considered potentially harmful to human health or capable of interfering seriously with the use of the water or its immediate environment. Most of the information available on algae in relation to polluted water is limited to water containing treated or untreated domestic sewage and closely related organic wastes. The following account, therefore, will deal primarily with this type of water pollution.

The algae are affected by pollution in a number of ways. They may be discouraged from growing as a result of being deprived of sunlight; the substances may be toxic or may ecologically modify the physical or chemical environment sufficiently to retard or prevent growth; they may suddenly have competition with additional organisms; certain algae may be stimulated to increased growth and multiplication; a change may also occur in the individual types or the groups of organisms that predominate (1); some algae may form blooms; the total algal population may be increased or decreased; oxygen production and utilization of nutrient substances by algae may be greatly modified; and the color, odor, and taste of the water may be changed by the algae.

Household sewage contains many kinds of organic material together with products formed from their partial, preliminary decomposition. In addition, the phosphates from detergents and small amounts of other wastes will be present (2). The relative effect on algae of each constituent in the complex mixture has not been determined. Studies have shown that the sodium triphosphate ingredient of a synthetic detergent stimulates the growth of the unicellular green alga, *Chlorella* (3).

In one river polluted with sewage, it was calculated that the phytoplankton contributed an average of 38 percent of the particulate organic matter from May to November (4).

After domestic sewage or effluent has polluted a body of water such as a stream, the algae present react in a manner that is of considerable importance. During the process of natural purification, the algae oxygenate the water and also utilize byproducts of the purification process. The kinds and numbers of algae and other organisms in the sewage-polluted portion of a stream are different from those present in the unpolluted portion above the sewer outlet. As the sewage goes through stages of decomposition in the stream, the numbers and kinds of microorganisms continue to change until eventually the aquatic flora and fauna in the newly purified water become somewhat similar to those found above the point of pollution. The algae represent a conspicuous and significant group in this continuously changing population in a stream. The variation in the algal population at different points or under different conditions of organic pollution constitutes one of the indices that can be applied to any desired location in the stream to determine the presence or absence of domestic sewage or other putrescible wastes or to measure the degree of recovery from pollution with these wastes.

After examining the reports of 165 authors, the writer has compiled a list of more than 850 names of algae commonly found in water containing a high concentration of organic wastes (1). Fifty of the more important species are listed in table 11, and 23 appear on plate IV.

Many genera of algae include certain species that tolerate organic enrichment and others that do not. This is particularly true of *Chlamydomonas, Euglena, Navicula, Oscillatoria, Phormidium,* and *Synedra.* In a few instances, it may also be true of strains or varieties of a species. For example, Fjerdingstad (5) claims that there are two separate strains of the species *Ulothrix zonata* (fig. 49), the pollution type and the pure water type.

Included in the group of pollution algae are some forms of unusual interest. Researchers say that *Euglena viridis, Nitzschia palea, Oscillatoria limosa* (fig. 50), and *Oscillatoria tenuis* (fig. 51) are more likely to be present than any other species when organic pollution exists (1). Next in order are *Arthrospira jenneri, Stigeoclonium tenue, Euglena gracilis,* and *Chlorella vulgaris. Anabaena constricta, Chlorella vulgaris,* and *Euglena viridis* are also found on sludge or in retention basins of sewage treatment plants. *Chlorella* grows readily in artificial culture media and is being used in a number of laboratories to determine the feasibility of producing algae on a large scale for food, animal feed, and other products. Two additional blue-green algae that tolerate organic enrichment are *Oscillatoria princeps* (fig. 52) and *Phormidium uncinatum* (fig. 53).

The blue-green algae and the flagellates are the algal groups most frequently encountered in the portion of a stream containing organic wastes. Not all representatives of the blue-green algae are actually blue-green; for example, the three species of *Oscillatoria* illustrated on plate IV tend to be decidedly yellow-green, although they belong to the above group. The flagellate green alga, *Chlamydomonas,* is one of the very common organisms in water. Since this genus has a large number of species and other

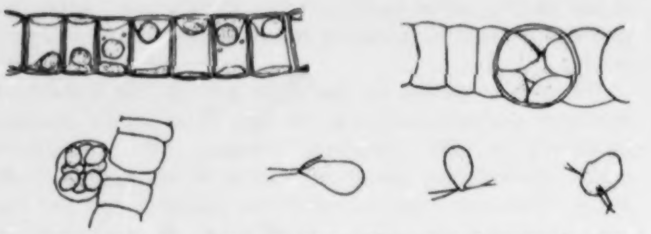


Figure 49.—*Ulothrix zonata*, vegetative filament and stages in spore production. Its two strains react differently to pollution.

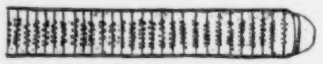


Figure 50.—*Oscillatoria limosa.*

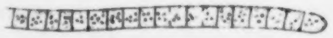


Figure 51.—*Oscillatoria tenuis.*

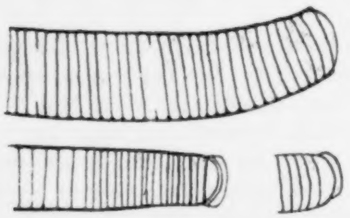


Figure 52.—*Oscillatoria princeps.*

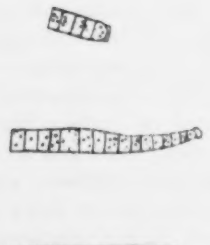


Figure 53.—*Phormidium uncinatum.*

algae have chlamydomonad stages, workers generally have not identified the particular species of *Chlamydomonas* they have encountered in polluted water. It is probable that there are a number of species other than the *Chlamydomonas reinhardi* shown on plate IV which could be listed as algae indicative of organic pollution.

Many of the non-swimming green algae with rounded cells are difficult to identify correctly and often have been mistakenly labeled *Protococcus* (name now changed to *Phytoconis)*, a type which is common on moist surfaces of tree trunks and which is attached and not normally planktonic. The two genera of green algae with rounded cells that are included here as pollution algae are *Chlorella* and *Chlorococcum*, both of which are illustrated on plate IV.

Some common industrial wastes are organic in nature but generally differ from household sewage in that they are composed primarily of one or more groups of organic compounds, or at least much less of a mixture than is household sewage. Examples would be the whey from dairy product processing plants, the blood and other animal products from slaughter and meat packing plants, the saw dust from saw mills, the discarded materials from canning factories, the beet particles from the sugar beet industry, mash from distilleries, and the lime, pulp screenings, filter slurry, lignans, and other carbohydrates from pulp and paper factories. Practically all of these pollutants tend to stimulate the growth of particular kinds of yeasts, bacteria, molds, and protozoa but are likely to be harmful to the algae. The algae in sewage ponds receiving a large amount of any of the above wastes are not likely to function efficiently. High turbidity produced by some of them will reduce light penetration in the stream or lake and thus prevent algal activity (6-8).

Other industrial wastes are composed of inorganic chemicals. Included are those from steel mills, mining operations, and chemical manufacturing plants. Steel industry wastes contain strong acid in unneutralized steel-pickling liquor, oil, grease, phenols, dissolved and suspended iron salts, and oxides (9).

In lakes the wastes are often in areas where the currents are sluggish, so that the wastes do not disperse or float away. Mining operations generate such wastes as sulfides of various metals, acid, mine slimes from pulverized ore, and silt (including those from strip-mining and stream-dredging activities). Chemical plants may release many different chemicals, some of which are frequently toxic to aquatic life. Slimes, silt, and sludges produce turbidity and, when they settle, cover up and destroy bottom-dwelling organisms. Inorganic chemical wastes invariably have deleterious effects on aquatic organisms (10-12).

Oil refineries release surface films of oil, tars, and oily soda-lime water, sludge, ammonia, and phenols, which may sink to the bottom and destroy aquatic organisms. Oil wells may release, in addition to oil, salt brine capable of making life impossible for most fresh-water organisms (6, 10). Artificial gas plants and railroad yards also discharge oily wastes.

Pulp and paper mills, agricultural land users, textile plants, and leather processing plants generate wastes that contain both organic and inorganic ingredients. All of these wastes tend to produce high turbidity, frequently dark discoloration, often acids or alkalies, complex organic materials, and often mineral salts, some of which are algal nutrients. However, the high turbidity, the dark color of the water, and the strong acids or alkalies are generally sufficient to destroy the algal growth in spite of the additional nutrients.

Insecticides, herbicides, and fungicides applied to or sprayed over agricultural areas can enter a body of water or impinge on river bank forests and marsh areas. They may not always destroy the algae but may concentrate on or in them and thus affect other organisms higher up the food chain (10).

Excess irrigation water that drains back into streams brings much silt with it, builds up the mineral content, and frequently adds nitrogen, phosphorus, and other algal nutrients. Its most obvious influences are accelerated hardness and alkalinity in addition to the turbidity. Silt accumulations suppress benthic algae, and turbidity reduces the phytoplankton concentration (6).

Power plants and atomic energy plants generally use large quantities of stream water for cooling purposes. The warm waters from such plants should not be discharged in such a manner as to create a temperature block across the stream (13). A high water temperature tends to favor the proliferation of blue-green algae, a medium temperature encourages green algae, and a low temperature is beneficial to diatoms. Certain species of blue-green algae, primarily *Oscillatoria,* are the most heat-tolerant organisms. Green filamentous algae tend to grow more rapidly in areas of heated water during spring and early summer (13).

Algae are able to accumulate the radioactive materials which later could affect other organisms that use algae directly or indirectly as food (14). One investigator found that the concentration of radio-phosphorus in phytoplankton had reached 200,000 times that in the surrounding water and the concentration in *Spirogyra* was 850,000 times that in the water (15).

Important physical and chemical characteristics of water which pollutants tend to change are turbidity, temperature, color, radioactivity, organic compounds, BOD, acidity, alkalinity, DO, minerals, oil, sludge, herbicides, and pesticides.

Particularly in the case of sewage pollution (and to some extent with regard to industrial organic wastes), algae and bacteria (and to a lesser extent, other organisms) are capable of bringing about the self-purification of water, especially in streams. Some kinds of algae are tolerant to sewage, that is, they are able to survive in its presence and may even be capable of growing and multiplying. For the most part, these algae utilize the nitrogen and phosphorus salts that are present, and in growing vigorously they carry on photosynthesis and release oxygen into the water as a byproduct. Sewage-polluted water is low in DO, since bacteria have already used what oxygen was present in initiating the decomposition of organic wastes.

The oxygen added by the algae permits the bacteria to continue decomposing the sewage. The waste products produced include ammonia, nitrates, and phosphates, which immediately serve as additional nutrients for the algae. Thus the algae stimulate the bacteria and the bacteria stimulate the algae. Both types of organisms increase rapidly in numbers, and the breakdown of the sewage is therefore enhanced. Unsightly, partially insoluble, turbid, gray, unstable, odoriferous material is changed into simpler, soluble, odorless, stable, clear, colorless, inorganic compounds.

During this process, the stream can conveniently be divided into several zones. The zone of degradation, also known as the polysaprobic zone, is the area just below the source of the pollutant. Most of the sewage there has not yet decomposed, non-tolerant algae and other organisms are being destroyed, and the DO is at or near zero. The next area is the zone of active decomposition, also designated the alpha-mesosaprobic zone, where bacteria and sewage-tolerant algae begin to flourish and the sewage is in the process of active decomposition. The third area is the zone of recovery or the beta-mesosaprobic zone, where the water becomes clear and offensive odors are absent. Algae are abundant while bacteria are decreased in numbers. Sewage is in the final stages of decomposition. The final area is known as the zone of cleaner water, also called the oligosaprobic zone, because the stream has been purified of sewage. Algae intolerant of sewage return, and sewage-tolerant algae decrease in numbers.

Various writers draw lines in slightly different places between the above zones. The description above represents the general distinctions among them (16).

Published records indicate that algae are most likely to be present in each zone (16). The general tendency is for diatoms to be common in the cleaner water, for blue-green algae and pigmented flagellates to be predominant in the zone of degredation and the first part of the zone of active decomposition, and for the green algae to prevail in the remainder of the zone of active decomposition.

Streams and lakes which have been polluted with organic compounds gradually become richer in algal nutrients, especially nitrates and phosphates, which are incorporated into the cells of algae during the self-purification process. As algae die the nutrients are released into the water after the algal protoplasm decomposes. This often stimulates the rapid development of nuisance algae that may form blooms or surface mats, cause taste and odor problems, and clog filters and screens in water treatment plants. It may also interfere with fishing, boating, swimming, and fish culture. In some cases the nuisance algae are toxic to both man and animals. They also make the body of water unsightly (17).

It is essential, therefore, to emphasize the great need for reducing the pollution load in streams and lakes by developing sewage treatment plants and processes for treating wastes. Tertiary sewage treatment is now being tried in which phosphates are removed before the effluent flows into the water. This would rob the algae of one of the essential nutrients required for growth (18).

Through concerted efforts the Willamette River in Oregon and the Connecticut River in New England have been changed from two of the most polluted streams in the nation to water courses that are approximately records of cleanliness. They serve to demonstrate that streams can be cleaned up and freed of pollution.

It is obvious that there are numerous relationships between various types of water pollution and algae. These have been considered separately but various combinations of these are often encountered, making it difficult to determine what the combined effect will be.

REFERENCES

1. A composite rating of algae tolerating organic pollution. C. M. Palmer. Jour. Phycology 5:78-82. 1969.
2. Microbiology of water and sewage. P. L. Gainey and T. H. Lord. Prentice-Hall, Inc., N.Y., 430 p. 1952.
3. Detergent phosphorus effect on algae. T. E. Maloney. Jour. Water Pol. Contr. Fed. 38:38-45. 1966.
4. Phytoplankton, seston and dissolved organic carbon in the Little Miami River at Cincinnati, Ohio. C. I. Weber and D. R. Moore. Limnolog. and Oceanog. 12:311-318. 1967.
5. The microflora of the River Molleaa with special reference to the relation of the benthal algae to pollution. E. Fjerdingstad. Folia Limnologica Scandinavica, No. 5, 123 p. 1950.
6. Some aspects of water pollution in the Missouri basin. J. R. Neel. In Biological Problems in Water Pollution. C. M. Tarzwell (ed.), U.S. Dept. Health, Education and Welfare, Pub. Hlth. Serv., Robt. A. Taft San. Engr. Center, Cincinnati, Ohio, p. 209-214. 1957.
7. Certain limnological features of a polluted irrigation stream. J. K. Neel. Trans. Amer. Microscop. Soc. 72:119-135. 1953.
8. The chemistry and biology of milk waste disposal. T. F. Wisnieuski. Jour. of Milk and Food Tech. 11:293-300. 1948.
9. Report on water pollution study of Mahoning River Basin, Water Pollution Control Unit. Sanitary Engineering Division, Ohio Department of Health, 91 p. 1954.
10. The effect of pollution upon wildlife. O. L. Mechean. In Biological Problems in Water Pollution. C. M. Tarzwell (ed.), U.S. Dept. Hlth., Educ., Welf., Pub. Hlth. Serv., Robt. A. Taft San. Engr. Center, Cincinnati, Ohio, p. 240-245. 1957.
11. Effects of turbidity and silt on aquatic life. J. N. Wilson. In Biological Problems in Water Pollution. C. M. Tarzwell (ed.), U.S. Dept. Hlth., Educ., and Welf., Publ. Hlth. Serv., Robert A. Taft San. Engr. Center, Cincinnati, Ohio, p. 235-239. 1957.
12. Aquatic life in waters polluted by acid mine waste. J. B. Lackey. Pub. Hlth. Repts. 54:740-746. 1939.
13. Effects of cooling water from steam-electric power plants on stream biota. F. J. Trembley. In Biological Problems in Water Pollution. C. M. Tarzwell (ed.), U.S. Dept. Health, Education, and Welfare, Pub. Hlth. Serv., RATSEC, Cincinnati, Ohio, Third Seminar 1962. Pub. Hlth. Serv. Publ. No. 999-WP-25. p. 334-345. 1965.
14. Pollution problems created by power reactors and other uses of atomic energy. C. P. Straub. In Biological Problems in Water Pollution. C. M. Tarzwell (ed.), U.S. Dept. Health, Education, and Welfare, Pub. Hlth. Serv., Robt. A. Taft San. Engr. Center, Cincinnati, Ohio, 2nd Seminar. W60-3. p. 33-39. 1960.
15. The practice of water pollution biology. K. M. MacKenthun. U.S. Dept. of Interior, Fed. Water Pol. Contr. Admin., Div. of Tech. Support. 281 p. 1969.
16. Self-purification of streams (Chapter 12) and ecological classification of microscopic organisms (Chapter 32). In the Microscopy of Drinking Water. G. C. Whipple, G. M. Fair, and M. C. Whipple. 4th ed. J. Wiley and Sons. p. 313-336 and p. 540-557. 1948.
17. The problem of nuisance growths due to organic enrichment. H. Heukelekian. In Biological Problems in Water Pollution. C. M. Tarzwell (ed.), U.S. Dept. of Health, Education, and Welfare, Publ. Hlth. Serv., Robert A. Taft San. Engr. Center, Cincinnati, Ohio, 2nd Seminar. W60-3. p. 250-251. 1960.
18. Phosphate extraction process. O. E. Albertson and R. J. Sherwood. Jour. Water Pol. Contr. Fed. 41:1467-1490. 1969.

TABLE 11. POLLUTION ALGAE—ALGAE COMMON IN ORGANICALLY ENRICHED AREAS

Group and algae	Plate or figure
Blue-Green Algae (Myxophyceae):	
Agmenellum quadriduplicatum, tenuissima type	IV
Anabaena constricta	IV
Arthrospira jenneri	IV
Oscillatoria chalybea	VIII
Oscillatoria chlorina	IV
Oscillatoria formosa	
Oscillatoria lauterbornii	IV
Oscillatoria limosa	29
Oscillatoria princeps	VIII
Oscillatoria putrida	IV
Oscillatoria splendida	VIII
Oscillatoria tenuis	30
Phormidium autumnale	IV
Phormidium uncinatum	II
Green Algae (nonmotile Chlorophyceae):	
Actinastrum hantzchii	
Ankistrodesmus falcatus	35
Chlorella pyrenoidosa	VIII
Chlorella vulgaris	IV
Closterium acerosum	
Coelastrum microporum	I
Micractinium pusillum	I
Pediastrum boryanum	I
Scenedesmus obliquus	67
Scenedesmus quadricauda	I
Stigeoclonium tenue	IV
Diatoms (Bacilariophyceae):	
Cocconeis placentula	III
Cyclotella meneghiniana	VIII
Diatoma vulgare	VIII
Gomphonema parvulum	IV
Hantzschia amphioxys	
Melosira granulata	VIII
Melosira varians	
Navicula cryptocephala	
Navicula viridula	
Nitzschia acicularis	
Nitzschia palea	IV
Nitzschia sigmoidea	
Stephanodiscus hantzschii	I
Surirella ovata	
Synedra acus	VIII
Synedra ulna	VII
Flagellates (Euglenophyceae, Volvocales of Chlorophyceae, others):	
Chlamydomonas reinhardi	IV
Chlorogonium elongatum	
Chlorogonium euchlorum	IV
Cryptomonas erosa	
Eudorina elegans	I
Euglena acus	
Euglena agilis	
Euglena deses	
Euglena gracilis	I
Euglena oxyuris	
Euglena polymorpha	
Euglena viridis	IV
Lepocinclis ovum	
Lepocinclis texta	IV
Pandorina morum	VII
Phacus pleuronectes	I
Phacus pyrum	IV
Spondylomorum quaternarium	
Synura uvella	VII

CHAPTER X

ALGAE AND POLLUTION—ESTUARINE

An estuary is the area where a river or stream meets the tide of the ocean. As the waters of the two generally do not mix quickly but remain temporarily as separate layers, the estuary may extend up the river channel for a considerable distance and also out into the ocean. Because of this resistance to sudden mixing, the nature of the environment, and the differences between the two waters, there tends to be a great variation in the conditions present at different locations in the estuary and at the same location at different times. The more important factors would include wave action, tides (causing periodic immersion), temperature differences between river and ocean waters and between seasons, the physical nature of the substratum, salinity, the nitrate and phosphate content of the waters, and the degree of turbulence and wind that exists (1). Many estuaries are shallow, and this factor stimulates the rapid cycling of nutrients between organic and inorganic phases. Thus, the principal feature of an estuary is the exceeding variability of its environment (2).

The algae of estuaries are of three major types, sea weeds, phytoplankton, and benthic forms including periphyton. The sea weeds may be attached to rocks along the shore or may be on the bottom covered by considerable depth of water. Often they become detached and can be collected using a boat with the aid of a net. Since the organisms inhabiting the estuary are subjected to a constantly changing environment, they are naturally tolerant to and able to withstand a rugged environment. *Pelvetia* is an example of a brown sea weed that can remain alive while uncovered by the water for long periods of time. *Ceramium, Polysiphonia,* and *Porphyra* are common red sea weeds (3).

Of the phytoplankton, diatoms rank first in abundance and photosynthetic activity. Dinoflagellates are generally considered second to diatoms as primary producers, particularly in warmer waters. The nannoplanktonic phytoflagellates also appear to be very common and abundant, but they are difficult to study, and many workers have, therefore, overlooked them. Examples of common genera are the diatoms, *Chaetoceros, Coscinodiscus, Navicula,* and *Rhizosolinea*. Common dinoflagellates include *Gymnodinium, Katodinium,* and *Heterocapsa*. Other common flagellates are *Olithodiscus, Chlamydomonas,* and *Chroomonas* (2). Examples of benthic forms are such blue-green algae as *Microcoleus* and the red flagellate *Dunaliella* (1).

Even when unpolluted, marine waters are extremely hard as compared to most inland waters. The total dissolved solids content is measured in terms of parts per thousand rather than parts per million. Water in the ocean ranges from 33 to 35 parts per thousand of total salinity.

Almost all estuaries are polluted because they receive the accumulated pollution of streams and lakes and contain the wastes dumped directly into them, including industrial, household, and oil materials. Wastes that are present or dumped into the open ocean are often carried back into estuaries.

While formerly neglected, more and more concern is being expressed about estuarine pollution since the areas involved are of increasing significance. Approximately one third of the population of the United States lives near estuaries, and seven of the world's 10 largest cities are on estuaries (4). Estuaries are habitats of both fin and shellfish and support huge commercial and sport fisheries. Estuaries provide bathing, sailing, and power boating and are also of great aesthetic value. Finally, industries draw large quantities of brackish water from them for cooling and processing purposes. All of these activities depend in some degree upon the quality of the water available (5). "To see the effect of pollution at its worst, one must as a rule go to the estuaries and tidal waters . . . . There is a feeling that once polluted water has left a river it goes away to sea and there gradually oxidizes where it does no one any harm . . . . [However] the next tide brings much of the pollution in again and the part that gets out seems to travel along the coast with succeeding tides coming backwards and forwards as the ocean currents carry it, until it finally oxidizes away." (6)

Since estuarine algae can withstand moderately large changes in the natural environment, the effects of pollutants must dominate the natural effects in order to be detected. Color plate V contains illustrations of 24 pollution-tolerant estuarine algae selected from a much larger number of species that have been reported. Represented in the group are brown, red and green sea weeds, diatoms, blue-green algae, dinoflagellates, various other pigmented flagellates, and one attached prostrate form.

In summer, diatoms often appear to be able to utilize the nutrient salts in highly polluted water. It is interesting that dinoflagellates play such an important part in the plankton of polluted water, whereas in fresh water they are practically absent in polluted areas. Green flagellates, such as *Eutreptia* and *Chlamydomonas,* thrive in highly polluted water but are very scarce in unpolluted estuaries (7).

Discharges into Boston Harbor caused very high concentrations of ammonia nitrogen (N) and soluble phosphorus (P) that often exceeded 100 and 40 micrograms per liter respectively in all reaches of the harbor. Dense populations of phytoplankton, averaging more than 1,000/ml, were present in about 66 percent of this harbor. Other estuarine waters having phytoplankton populations denser than 1,000/ml are considered to be over-enriched.

Sewage pollution also stimulates dense growths of attached sea weeds which give off noxious odors, cause unsightly growths at marine facilities, and increase the costs of maintaining buoys and piers. In some cases, decomposing masses of *Ulva* (sea lettuce) have emitted enough hydrogen sulfide to discolor paint on nearby buildings (8). The discharge of pollutant-laden water from duck farms into Long Island Bay has allowed large numbers of the green alga *Codium* to develop as a bottom-attached form. This plant seriously interferes with the development of shellfish.

Pollutants which reach an estuary may be oxidized with the aid of oxygen produced by the algae during photosynthesis, may settle to the bottom, or may be carried out to sea. In shallow estuaries, the benthic algae may aid in further decomposition of the sludge deposits.

The prevention or reduction of estuarine pollution is dependent primarily upon stopping or modifying the dumping of pollutants into estuaries and the bodies of water that flow into them.

REFERENCES

1. Ecology of marine algae. J. Feldman. Chapt. 16 in Manual of Phycology by G. M. Smith (ed.), Chronica Botanica Co., Wallham, Mass., p. 313-334. 1951.
2. Studies in brackish water phytoplankton. P. H. Campbell. Sea Grant Publication UNC-SC-73-07, Univ. N. Carolina, 409 p. 1973.
3. Algal vegetation types along the shores of inner bays and lagoons of Curacao, and of the lagoon lac (Bonaire), Netherlands Antilles. C. van den Hock, F. Colijn, A. M. Cortal-Breeman and J. B. W. Wanders. Verhandelingen der Komnklijke Nederlandse Akademie van Wetenschappen, afd. Natuurkunde. Tweede Reeks, Deel 61. No. 2:1-72. 1972.
4. Hydrographic factors involved in the dispersion of pollutants introduced into tidal estuaries. D. H. J. Hull. Proc. 34th Ann. Conf., Maryland-Delaware Water and Sewage Assn., p. 37-52. 1961.
5. Algal and organic waste assimilation in tidal estuaries. D. H. J. Hull. Proc. 34th Ann. Conf., Maryland-Delaware Water and Sewage Assn., p. 37-52. 1961.
6. The danger of estuary pollution. Chapt. 1 in River Pollution. H. D. Turing. E. Arnold & Co., London, p. 9-35. 1952.
7. A phytoplankton survey of the polluted waters of Inner Oslo Fjord. T. Braarud. Hvalraadets Skrifter, Scientific Results of Marine Biological Research. No. 28:1-142. 1945.
8. The practice of water pollution biology. K. M. MacKenthun. Fed. Water Pol. Contr. Admin., Div. of Tech. Support. 281 p. 1969.

CHAPTER XI

ALGAE AS INDICATORS OF WATER QUALITY

Changes in water quality exert a selective action on the flora and fauna which constitute the living population of water, and the effects produced in them can be used to establish biological indices of water quality. Changes in water quality may affect the amount of oxygen and nutrients present or cause the water to become toxic to some types of organisms. The change may result from the amount of inert solids present in the water. In studying and observing any particular body of water, the aquatic biologist applies certain types of measurements, such as a biological index, to obtain information about the conditions that are present (1).

In the past, chemical, physical, and bacteriological criteria were considered to be easier to evaluate and apply than biological indices, which were thought to be relatively underdeveloped (2). Chemical and physical measurements, however, tend to measure only the cause of change in water quality, while biological tests deal primarily with effects of the change. Simple, rapid, and reliable methods for assessing the degree of purity or contamination of water have now been developed to such an extent that certain of them will soon merit consideration as standardizable procedures, applicable over a wide range of waters.

There are in general two types of biological tests:

1. All organisms present in a water sample are identified and their relative frequency is established. These tests are direct or ecological ones and can deal with all kinds of organisms present, or they may be limited to a few groups, one group, or one or a few types of individuals.

2. Indirect or physiological methods are used to estimate the living activity of the organisms. They may be limited to a particular species or test organism, which is cultured in the laboratory and inoculated into a sample of water to be tested. Certain selected reactions serve as indices of water quality (3).

The classic direct or ecological test is the saprobity system of Kolkwitz and Marsson (4), which has been revised by several other workers, including Liebmann (5). Originally the indicator species found in a sample were merely listed and the list was used to define the particular zones of pollution. Indicator species had previously been designated as belonging to four water quality zones: oligosaprobic (clean), beta-mesasaprobic (sub-pollutional), alpha-mesasaprobic (pollutional), and polysaprobic (septic). Some modifications of the procedure have been developed, especially those involving the relative frequency of each species. Statistical calculations were also introduced, allowing the results to be expressed on graphs. One procedure that is considered convenient has been adopted as a preliminary standard procedure in East Germany. Each species is assigned a number from 1 to 4 in a sample of water from a particular location. The number is based on its position in the saprobity system and its frequency (3). The oligosaprobic zone organism is $s = 1$ and so on through the 4 zones. Frequency (h) is divided into three: rare = 1, common = 3, and abundant = 5. The saprobity index (S) can be calculated for each sampling area by the following formula: $S = \frac{s \cdot h}{h}$. The saprobity index for each degree of pollution is as follows:

Saprobity index	*Degree of pollution*
1.0 - 1.5	Very slight
1.5 - 2.5	Moderate
2.5 - 3.5	Heavy
3.5 - 4.0	Very heavy

Various other modifications have been made such as subdividing the water quality zones (6,7), comparing the number of chlorophyll-bearing organisms (producers) with the number of non-chlorophyll-bearing organisms (consumers). In one of these a biological index of pollution (BIP) is calculated by the formula

$$\text{BIP} = \frac{B}{A+B} \times 100$$

where A represents the producers (algae) and B represents the consumers (protozoa). Individual non-filamentous bacteria and other organisms are not used. The following BIP numbers are examples fitting into the various water quality zones: 0.6 = zone of clean water, 12.0 = zone of moderate decomposition, 30.9 = zone of active decomposition, and 55.1 = septic zone (8).

In 1969, a procedure was described for using the 20 genera or species most emphasized by workers as being tolerant of high organic pollution to determine the algal pollution index of a sample of water. Five of these genera, *Synedra, Nitzschia, Melosira, Pandorina,* and *Euglena,* are illustrated in figures 54-57. For each of the 20 algae, a pollution index factor was assigned (see table 12). In making a microscopic analysis of a sample, all of the 20 algae that are observed are recorded (providing 5 or more individuals, per slide, of a particular kind are present). The index factors of the algae present are then totaled. A score (pollution index) of 20 or more is taken as evidence that high organic pollution exists, while a score of 15 to 19 represents probability. Lower figures indicate that the organic pollution of the sample is not high, that the sample is not representative, or that some substance or factor interfering with algal growth is present (9).

In some cases particular groups of algae have been used to indicate the quality or type of water. Lakes have been characterized in terms of their dominant phytoplankton groups. Many desmid species are most frequent in oligotrophic waters, while a few are most frequent in eutrophic bodies of water. Many blue-green algae occur in nutrient-poor waters, while others are tolerant of high organic pollution (10).

A diatometer has been developed and used to nonselectively and continually sample a diatom flora. The diatometer holds microscope slides that are immersed in the surface water and are removed after predetermined periods of time. The diatoms collected are first processed, then fixed on clean slides, and identified and counted under the microscope. A graph is made in which the ordinate equals the number of species on an arithmetic scale and the abscissa represents the numbers of specimens whose intervals are on a logarithmic scale. A truncated normal curve is constructed which best fits the data.

When the diatom flora has been adversely affected by slight pollution, the length of the curve is extended. Furthur pollution causes a reduction in the height of the mode. By means of this procedure it is possible to spot the badly polluted areas in a body of water (11).

Diatom associations have also been selected as indicators of the presence of certain industrial wastes and of sewage. Particularly emphasized have been species and varieties of *Gomphonema* (12,13).

Through species numbers of diatoms, the ecosystem approach to water quality assessment has been used. At eutrophic stations, a few species generally compose a large portion of the diatom population and their density level is usually high. "Clean" stations, on the other hand, have more species that compose a small portion of the total diatom population and the overall density level is low. For example, over a 27-month period, the average number of species of diatoms present in random counts of 250 to 300 organisms at Buffalo, where the water was of very poor quality, was only 12. In contrast, during the same period, the average for Sault Ste. Marie, which has high quality water, was 41 (14).

Navicula accomoda is claimed to be an indicator of sewage pollution, a position not occupied by any other species of diatom. Other species may be present but are not limited to the alpha-mesosaprobic zone as this form seems to be (15).

The red-colored blue-green alga, *Oscillatoria rubescens*, develops suddenly in large numbers, discolors the water, and is considered, especially in Europe, as the first acute indication that a lake is undergoing a distinctly unfavorable development. Later symptoms include turbidity, disagreeable odor, and disappearance of the higher grade fish (16).

Five algae were selected as reflecting the amount of pollution in rivers in England. *Stigeoclonium tenue* is present at the downstream margin of the foulest part of a river, *Nitzschia palea* and *Gomphonema parvulum* always appear to be dominant in the mild pollution zone, and *Cocconeis* and *Chamaesiphon* are almost always found in unpolluted streams or in the repurified zone (17).

In estuarine waters, a certain few algae are claimed to be indicators of pollution. When the population is large, *Peridinium triquetum* may be used as a reliable indicator that the water is highly contaminated. There is hardly any other species which is so characteristic of polluted waters as is *Eutreptia lanowli*. It is considered remarkable that dinoflagellates play such an important part in the plankton of estuarine polluted waters. In fresh water the dinoflagellates are practically absent in the polysaprobic and mesosaprobic regions (18).

Indirect or physiological tests are being used with increasing frequency to study the potential fertility of water. In 1927, a procedure was described in which a species of *Carteria* was used as a test organism in sea water to determine the phosphorus and nitrogen content. From the results it could be determined what combination of salts was the limiting nutrient factor for the growth of phytoplankton in the area tested.

For fresh water, the unicellular green alga *Selenastrum capricornutum* has several superior qualities as a laboratory organism: (1) it is easy to identify; (2) form variations with changing growth conditions are small; (3) it is solitary; (4) it is an obligate autotroph; and (5) it has a minimum of growth requirements. It has been used in Norway and the test procedure is as follows:

1. Water samples are autoclaved and inoculated from a culture of *Selenastrum*.
2. The flask is shaken slowly at 30°C and illuminated by flourescent lights.
3. The extent of growth of the alga is determined by measuring the red flourescence due to chlorophyll. The results, which are compared with those obtained using a standard solution, indicate the amount of fertilizing substances present in the water (19).

A culture test was developed in Vermont in 1956 to determine the nutrients available for plant growth in natural waters using a pure culture of the green alga *Kirchneriella subsolitaria* (fig. 58) as the indicator organism. Six samples of the natural water are inoculated with *Kirchneriella*. One sample serves as a control and sodium carbonate, calcium carbonate, diacid potassium phosphate, magnesium sulfate, or all four are added to the remainder. Cell counts are made daily and population densities are estimated by statistical techniques (20).

Due to rapidly increasing concern for the problems generated by eutrophication and pollution, it is essential that acceptable standardized algal growth tests be developed to measure these conditions. A Joint Industry/U.S. Government Task Force on Eutrophication determined

Figure 54.—*Synedra* and *Nitzschia*.

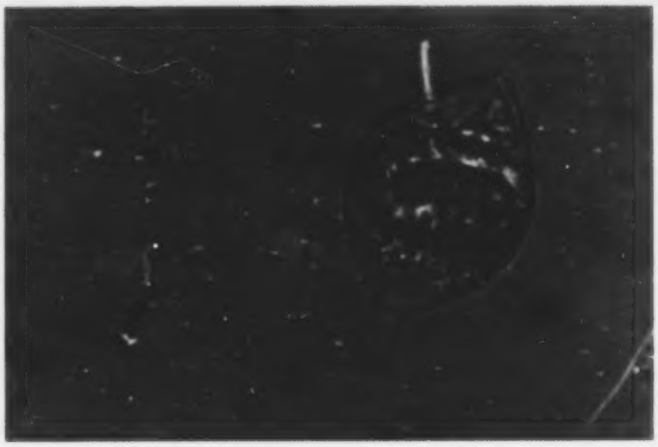


Figure 57.—*Euglena* (indicator alga).

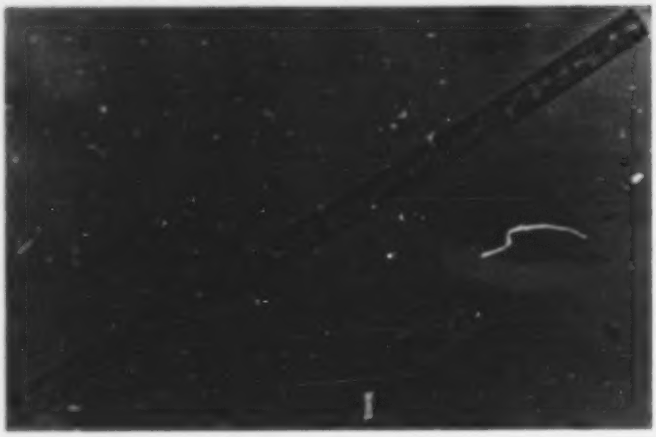


Figure 55.—*Melosira* (indicator alga).

Figure 58.—*Kirchneriella subsolitaria*, the alga used in the Vermont test.

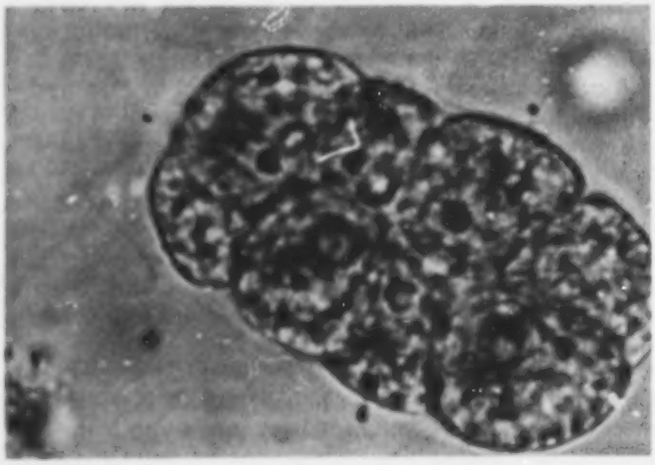


Figure 56.—*Pandorina* (indicator alga).

in 1969 that there should be provisionally three fundamental test algal assay procedures: a bottle test, a continuous-flow-chemostat test, and an in situ test. After about two years of research, it was decided that the bottle test was reliable and ready for routine use. Further research is needed on the other two tests before they become ready for universal use.

Three standard test organisms are recommended for the bottle test, *Selenastrum capricornutum, Anabaena flos-aquae,* and *Anacystis cyanea (Microcystis aeruginosa).*

A sample of unknown strength from some water source can be assayed in comparison to media of known strength. Further evaluation is needed to refine the technique.

Bottle algal assays consist of three steps:

1. Selection and measurement of appropriate parameters during the assay, for example, biomass indicators such as total cell carbon, maximum specific growth rate, and maximum standing crop. Determination of the algal growth may be accomplished by several methods such as dry weight, direct microscopic counting, use of an electronic particle counter, absorbance with a spectrophotometer or colorimeter at a wave length of 600-750 mμ (millimicrons), chlorophyll content by direct fluorometric determination or total cell carbon.
2. Presentation and statistical evaluation of the measurements made during the assay.
3. Interpretation of the results with respect to the specific problem being investigated.

It is intended that the test be used to: (1) identify algal growth-limiting nutrients; (2) determine biologically the availability of algal growth-limiting nutrients; and (3) quantify the biological response to changes in concentration of algal growth-limiting nutrients. These measurements are made by adding a selected test alga to the test water and determining algal growth at appropriate intervals (21).

The methods using algae as indicators of water quality vary, therefore, from identifying the algal flora of the sample of water, detecting one or a few forms or groups, to culturing a selected test alga in the water being studied. Books giving precise descriptions of techniques in which algae are used to measure the quality of surface waters and effluents are Biological Field and Laboratory Methods (22), Handbook of Phycological Methods (23), and Standard Methods for the Examination of Water and Wastewater (24). Progress toward the selection in standardization of one or more of these methods is being made in Europe and the United States.

REFERENCES

1. The biological indices of stream quality. W. M. VanHorn. Proc. Fifth Indus. Waste Conf., Purdue Univ. 1949. Purdue Univ. Eng. Bull. 34:215-222. 1950.
2. California water quality criteria. State of California. 1952.
3. A review of central European methods for the biological estimation of water pollution levels. H. Bick. Bull. World Health Organization 29:401-413. 1963.
4. Oekologie der Saprobien. Uber die Bezeihungen der Wasserorganismen zur Umwelt. R. Kolkwitz. Schriftenreihe des Vereins für Wasser-, Boden-, und Lufthygiene Berlin-Dahlem/Gegründet im Jahre 1902. Herausgegeben im Auftrage des Vereins für Wasser-, Boden-, und Lufthygiene von Prof. Dr. E. Tiegs, Nr. 4. 64 p. 1950.
5. Handbuch der Frischwasser und Abwasserbiologie. Band 1. H. Liebmann. R. Oldenbourg, München, Germany, 539 p. 1951.
6. Water quality system. V. Sladecek. Verh. Internat. Verein. Limnol. 16:809-816. 1966.
7. Pollution of streams estimated by benthal phytomicro-organisms. I. A saprobic system based on communities of organisms and ecological factors. E. Fjerdingstad. Int. Revue Ges. Hydrobiol. 49:63-131. 1964.
8. A preliminary report on the biological index of water pollution. I. Horasawa. Zool. Mag. (Tokyo) 54:37-38. 1942.
9. A composite rating of algae tolerating organic pollution. C. M. Palmer. Jour. Phycol. 5:78-82. 1969.
10. Planktonic algae as indicators of lake types, with special reference to the Desmidiaceae. A. J. Brook. Limnol. and Oceanog. 10:403-411. 1965.
11. Diatoms as an indication of river change. R. Patrick. Proc. 9th Indus. Waste Conf. 1954, Purdue Univ. Eng. Bull. 39:325-330. 1955.
12. Diatomaceas no trato digestivo do Australorbis glabratus (Say, 1818). H. M. Filko and D. M. M. Momoli. Botanica (Brazil), No. 9:1-7. 1963.
13. Diversity in some South African diatom associations and its relation to water quality. R. E. M. Archibald. Water Research 6:1229-1238. 1972.
14. Possible relationships between plankton-diatom species numbers and water-quality estimates. L. G. Williams. Ecology 45:809-823. 1964.
15. Notes on the ecology of the diatom *Navicula accomoda* Hustedt. E. G. Jorgensen. Saertryk af Botanisk Tidsskrift 49(1):189-191. 1952.
16. The Alpine lakes, a heritage in danger. O. Jaag. World Health Organization News Letter 8 (5):3. 1955.
17. Pollution and re-purification as indicated by the algae. R. W. Butcher. Fourth Internat. Congress for Microbiology, 1947. Rept. of Proc. p. 149-150. 1949.
18. A phytoplankton survey of the polluted waters of Inner Oslo Fjord. T. Braarud. Hvalraadets Skrifter, Scientific Results of Marine Biological Research. No. 28:1-142. 1945.
19. Algal problems related to the eutrophication of European water supplies, and a bio-assay method to assess fertilizing influences of pollution on inland waters. O. M. Skulberg. Chapt. 13 in Algae and Man. D. F. Jackson (ed). Plenum Press, N.Y. p. 262-299. 1964.
20. A biological test for determining the potential productivity of water. M. Potash. Ecology 37:631-639. 1956.
21. Algal assay procedure: bottle test. A. F. Bartsch (ed). National Eutrophication Research Program. Environmental Protection Agency. 82 p. 1971.
22. Biological field and laboratory methods for measuring the quality of surface waters and effluents. C. I. Weber. National Environmental Research Center. Office of Research and Development. U.S. Environmental Protection Agency, Cincinnati, Ohio. EPA Rept. No. 670/4-73-001. 187 p. 1973.
23. Handbook of phycological methods, culture methods & growth measurements. J. R. Stein (ed). Cambridge Univ. Press, London, England. 448 p. 1973.
24. Bio-assay methods for aquatic organisms. Part 800 In Standard Methods for the Examination of Water and Wastewater. Ed. 14. Amer. Pub. Hlth. Assn., Washington, D.C. p. 685-869. 1975.

TABLE 12. ALGAL GENUS POLLUTION INDEX

Genus	Pollution index	Genus	Pollution index
Anacystis	1	Micractinium	1
Ankistrodesmus	2	Navicula	3
Chlamydomonas	4	Nitzschia	3
Chlorella	3	Oscillatoria	5
Closterium	1	Pandorina	1
Cyclotella	1	Phacus	2
Euglena	5	Phormidium	1
Gomphonema	1	Scenedesmus	4
Lepocinclis	1	Stigeoclonium	2
Melosira	1	Synedra	2

CHAPTER XII

ALGAE IN SEWAGE STABILIZATION PONDS

There are several processes that have been developed for the treatment of municipal sewage. The three most commonly used methods are trickling filters, activated sludge systems, and lagoon systems. In total there are approximately 16,000 treatment plants in the United States. Of these, 4,000 are municipal wastewater lagoon systems, and more than 90 percent are used for communities of less than 10,000 population. With the exception of completely anaerobic lagoons used for pretreatment of certain industrial wastes, lagoons depend on algae to aid in the transformation of the sewage to a stable secondary effluent that can be released into the receiving water. The biological processes occurring in facultative lagoon systems are described in the following pages. Some lagoon systems are aerated through submerged tubing using air supplied by compressors installed in blower houses near the lagoon, or by mechanical aerators, but the biological processes remain similar to those of the facultative lagoon systems. The aerated lagoon systems are used where high concentrations of organic wastes may be anticipated or where extremely cold temperatures and ice cover over the lagoon system may restrict the activities of the algae during the winter period.

In the waste oxidation-stabilization method, liquid sewage is released into a man-made or natural pond before or after receiving preliminary treatment and is held there to permit desired microbiological transformation to take place. Algae, bacteria, and other microorganisms combine to change the waste into stabilized forms which are unobjectionable when discharged. The process can be so regulated that no offensive conditions occur during treatment (1).

Although bacteria are the most significant saprobic organisms, molds and yeasts may also be present. Molds are particularly abundant when the pH is low and in pond sludges and scums. Fungal colonies in a pond can reach a maximum of about 1 million colonies/gm dry weight of sludge and liquid (2).

If proper environmental factors such as light, temperature, and the absence of toxic materials (such as chromate) exist, 150 mg/l of BOD can be lowered to approximately 20 mg/l if sewage is kept in an oxidation-stabilization pond for about 15 days. Detention periods of 20 to 30 days are, however, generally recommended, and the initial BOD loading is commonly less than 150 mg/l (3).

This procedure has been accepted in many areas as a satisfactory method for disposing of household sewage and some types of industrial wastes. In a few states, for example, up to one-half or more of the communities are treating their wastes in this manner. Brazil is constructing additional oxidation-stabilization ponds for use in large cities as well as smaller towns. Warm climates stimulate rapid changes in the sewage and also permit deeper ponds and more concentrated loadings than are possible in the United States. In North America, the proper loading of sewage ponds has generally been considered to be from 25 to 50 lb BOD/acre-feet/day, and in Australia, about 70 lb (4,5). In the southern United States, loadings of 100 to 250 lb/acre/day have sometimes been used successfully. In Brazil, however, loadings up to about 700 lb are being used, sometimes with the aid of agitators or aerators, and often a deep primary pond. Intense sunlight may be a factor that permits this also. In the northern states where ice develops on the ponds in winter, the loading must be low enough to prevent problems of anaeoobic decomposition and odor production in the spring, when the ice melts and before the algae have developed in sufficient amount to stimulate aerobic activity. Odor problems can often be handled satisfactorily by adding sodium nitrate at the rate of 1 lb/lb of BOD (6).

The transformations in a stabilization pond correspond closely to the natural purification that occurs in a stream receiving organic wastes. Aerobic and anaerobic saprobic bacteria are available to act on the organic debris in the water and to break down the material into simpler compounds. In the presence of sufficient quantities of sewage, any dissolved oxygen in the water may be consumed very quickly. This generally limits the activities of the aerobic bacteria, and the aerobic process, therefore, comes to a standstill. In many cases, however, it is desirable to encourage the aerobic process and to limit the anaerobic, since the former can be faster and the amount of intermediate malodorous products is less than in the latter process.

When an anaerobic process is used as a part of the treatment in heavily loaded ponds, the relative areas of aerobic and anaerobic units should probably have a ratio of about 15 to 1 (7).

Products of the anaerobic process include sulfides, nitrogen gas, volatile acids, and methane, while products of the aerobic process include water, nitrates, phosphates, sulfates, and carbon dioxide. The latter products are more readily utilized by algae and other pigmented plants than are the former, and they are mostly odorless and generally soluble in water.

The sewage stabilization pond contains an algal population which is continually active and subject to substantial changes in number and constituent members. It thus tends to be very different from the algal populations present in stagnant pools, eutrophic ponds or lakes, and laboratory cultures. As soon as the population in the sewage pond changes in the direction of the type population of these other habitats, it is evidence that oxidation and stabilization in the pond are not functioning properly.

In a stabilization pond where there is a continuous replacement of sewage, the algae present must be capable of existing under the condition imposed by such an environment. In addition, they must be metabolically very active, absorbing carbon dioxide, nitrates, phosphates, and other nutrients from the pond and releasing an abundance of oxygen. This high activity is possible only in young algal cells. There must be continual, rapid reproduction of new algal cells into which the protoplasmic contents of the parent cells are completely incorporated into the cells of the new generation. Otherwise the increased algal catabolism, together with decomposition of old cells that die, will more than counteract the desirable changes brought about by the young algal cells in the pond. A static algal bloom on the surface of the pond or a slowly developing mass of attached algae on the sides or bottom is seldom found in a sewage pond where the algal population is functioning at its best.

In this report, all genera of algae recorded from the samples are classified as representatives of four groups which are often used in the field of sanitary biology. These are blue-green algae, diatoms, flagellate algae, and green algae. Typical examples of genera representative of the four groups found in stabilization ponds are blue-green algae: *Anacystis (Microcystis), Oscillatoria, Schizothrix;* diatoms: *Cyclotella, Gomphonema, Nitzschia;* flagellate algae: *Chlamydomonas, Euglena, Cryptomonas;* green algae: *Ankistrodesmus, Chlorella, Scenedesmus* (table 13).

Algae present in the sewage pond, because of their photosynthetic activity, release oxygen into the water and the oxygen is then available to increase the aerobic decomposition of the organic wastes by bacteria.

The rate of oxygen production by algae in daylight may be up to 20 times the rate of oxygen uptake by algae in respiration at night. Thus, even though the DO may go down to zero in sewage ponds at night, due to bacterial and algal metabolism, the DO of the pond may reach up to about 25 mg/l in the daylight because of algal photosynthesis.

Oxygen production in algal photosynthesis decreases with depth, e.g., it is often five times greater near the surface than at a depth of 2.5 ft. Thus, from this standpoint, the use of shallow ponds of about 2.5 ft would be the most efficient, since below that depth the amount of oxygen used in algal respiration is at least as much as the oxygen released by photosynthesis. Other factors such as temperature, water movement, and problems of weed control indicate that a pond 3 to 4 ft in depth would be desirable (8,9).

When illuminated, algae excrete no other gas than oxygen. Normally, only a minimal amount of soluble organic material is excreted and, therefore, in a living state, they do not increase the amount of organic matter in a pond (10). However, some forms of *Chlamydomonas* and *Scenedesmus* are known to excrete organic material. In some cases the former genus has excreted up to 40 percent of the oxidizable soluble material formed in algal photosynthesis (11).

Although many kinds of algae are sensitive to large amounts of organic wastes in their environment, others are tolerant and may be stimulated in their growth and reproduction by the presence of the wastes. These latter forms are often called pollution-tolerant algae or merely pollution algae.

Algae function in another significant way in a pond. The simpler compounds that result when aerobic bacteria decompose organic wastes include nitrates, ammonia, phosphates, and lesser amounts of other compounds, all of which are the nutrients algae require for growth. The pond water does not accumulate any large quantity of these nutrients, since they are quickly absorbed and assimilated by the algae. In this way, the chemical units that comprised the organic wastes are eventually incorporated into the algae as relatively stabilized organic components of living algal cells.

Ordinarily domestic sewage does not provide a balanced diet, since both carbon and nitrogen are deficient in relation to the amount of phosphorus normally present. Theoretically, therefore, it would increase algal growth if additional inorganic carbon (such as carbon dioxide) and nitrogen (such as ammonia nitrogen or sodium nitrate) were available to supplement the sewage in the pond.

Algae appear to offer the most easily exploited biological system for extracting phosphorus from domestic sewage. Tests indicate that algae can bring about phosphorus reductions of 0.8 to 2.0 mg/l. Laboratory and pilot plant studies indicate that in the presence of adequate amounts of light, soluble phosphate reductions equivalent to 90 percent or more can be achieved with contact times as brief as 6 to 12 hr (12). Another method of removing both phosphorus and nitrogen would be to increase the pH and thus precipitate the nutrients (13). Reports indicate that biological processes can effect a phosphorus reduction ranging from 83 to 92 percent (14). Much more research effort would be needed to optimize this type of removal process.

Considering the two functions of the algae, sewage ponds may be called oxidation ponds if the release of oxygen by algae is emphasized, or stabilization ponds if the assimilation of nutrients into stable living algal cells is stressed.

When the algae in the ponds die, their organic contents are subject to decomposition by saprobic bacteria. The death and decomposition at one time of large numbers of algae would again bring about nuisance conditions approximating those caused by the original sewage wastes placed in the pond. It is desirable, therefore, to prevent this by stimulating the algae to continue growing or by arranging for the algae to leave the pond continuously in moderate numbers.

The use of a sewage oxidation-stabilization pond permits control of a number of factors that affect the efficiency of treatment. The working capacity of the pond should be large enough to permit the optimum detention period for the concentration of wastewater that can be treated in the particular climatic zone. A shallow depth, often about 4 ft, is used so that sunlight may reach even the lower layers of water and thus allow algal photosynthesis to take place throughout the pond. The movement of water through the pond is controlled by regulating the rate and volume of flow of the effluent. It must also be determined whether to use the pond for primary, secondary, or tertiary treatment of the sewage. Some states have statutes that regulate the use of such ponds and allow only one type of treatment.

A study of many sewage ponds in widely scattered parts of the United States and other American countries indicates that of a total of 125 genera recorded, any one of approximately 15 may be a frequent and dominant form. Only two of these are diatoms and only two are blue-green algae. Five are pigmented flagellates; the remainder are nonmotile, nonfilamentous green algae.

A study of algae from sewage ponds was conducted throughout 18 states, the Panama Canal Zone, and the West Indies; all major areas of the United States were included. It covered 74 ponds, involved 929 sampling dates, and lasted for more than six years (15). The number of algal genera recorded per sample ranged from 1 to 33. Approximately one-third of the ponds had a maximum of 13 to 33 types per sample. Of the 125 recorded, roughly 50 percent were green algae, 25 percent were pigmented flagellates, 15 percent were blue-green algae, and 10 percent were diatoms. An example is *Achnanthes* (fig. 59).

A number of the algae are well represented in ponds throughout the country. Among the most abundant are (in decreasing order of abundance): *Chlorella, Ankistrodesmus, Scenedesmus, Euglena, Chlamydomonas, Oscillatoria, Micractinium, Golenkinia, Anacystis,* and *Oocystis* (table 14). *Chlamydomonas* has been the only genus abundant throughout the country, and *Chlorella* has been abundant in all but the southeastern states. Numerous flagellates and green algae appear to be limited in abundance geographically. Some algae unusual for sewage ponds have been recorded as follows: *Aphanizomenon* (ND), *Dinobryon* (Md), *Enteromorpha* (ND), *Fragilaria* (Md), *Gloeocystis* (NH), *Gonium* (Col), *Lyngbya* (ND), *Microspora* (Md), *Oedogonium* (Ind), *Pediastrum* (Col), *Pyrobotrys* (Oh), *Spirogyra* (ND), and *Zygnema* (Md).

At Lancaster, California, samples were obtained on 294 days during a period of over 6 years; 25 algae were very abundant in one or more instances. *Scenedesmus* was the most consistently abundant every year and every month. *Closteridium* was absent during the first year but reached a very high abundance in the last year, while *Chodatella* was present in large numbers during the first two years but almost disappeared during the last two years. *Euglena* also gradually became less abundant from the first to the last year.

Each pond tends to have a distinctive group of genera that generally is present week after week and distinguishes that pond from all others. Any change in the flora is likely to be gradual (16).

In some ponds in Africa, *Chlorella* was reported as being predominant in the first stage of treatment, but in the second stage its numbers fell off and *Spirulina* began to proliferate. In the third stage *Chlorella* had almost disappeared, and *Spirulina* predominated. Many other less prominent algae were present in all three stages (17).

At one pond in California, *Chlamydomonas* and related forms were dominant when the pH ranged from 7.0 to 7.7; *Euglena* was usually dominant where the pH ranged from 7.7 to 8.9; and *Chlorella, Scenedesmus,* and other related genera were abundant when the mid-day pH ranged from 8.4 to 9.8. A pH change caused a shift in the relative abundance of the various genera in the pond (18).

An examination of pond effluent for algae may give useful information. If it contains principally *Chlorella,* this indicates that the pond is working at or over its capacity. If it contains a mixed algal flora, and *Chlorella* is prominent only farther back in the pond, this suggests that the pond could handle a heavier load (11).

A number of the sewage pond algae are illustrated on plate IV and 23 more are shown on plate VI. The latter includes the green alga *Diacanthos,* which has possibly not been recorded previously in the United States. *Vacuolaria* has been considered rare for this country, and *Schizothrix,*

Figure 59.—*Achnanthes*, a sewage pond diatom.

as it is now called, has in the past been confused with certain species of *Oscillatoria* and other filamentous blue-green algae (19).

Table 15 indicates in a very general way the various conditions of sewage oxidation-stabilization ponds and the relationship of the ponds to number and types of algae, the pH, DO, BOD, and nitrogen reduction. Since these all vary in actual ponds, the table can be considered only as a guide (20).

Practically all of the common sewage algae tend to be planktonic, that is, they remain dispersed in the water and are unattached to other objects. Most of them do not tend to collect on the surface as a mat or bloom, although *Anacystis (Microcystis), Chlamydomonas,* and others occasionally do.

Problems caused by many blue-green algae in the summer generally can be handled if 2,3-dichloronaphthoquinone is applied at the rate of 1 ppm at the pond influent and around the water edges. Also the algal mats may be broken up by the use of an outboard motor (6).

As planktonic forms all of the sewage algae are well equipped in form and distribution to absorb sunlight, nutrient salts, and carbon dioxide and to release oxygen throughout the length and depth of the pond. Algae, when they concentrate as mats or blooms on the surface, are undesirable because they release most of their oxygen into the air. Algal communities remain about the same at various depths in the aerobic zone which indicates effective vertical mixing in the pond (21).

A few of the sewage pond algae, particularly certain strains of *Chlamydomonas, Pyrobotrys (Chlamydobotrys), Chlorogonium, Eugiena,* and *Chlorella,* have the unusual ability to utilize acetate in their photoassimilation. These algae produce little or no oxygen and are therefore inefficient in stimulating aerobic bacteria to act on sewage (22). There is no indication at present that these strains are a significant part of the flora of most sewage ponds.

Several of the algae are unable to develop in the presence of large amounts of certain organic wastes such as those from milk processing plants, food canneries, beet sugar factories, and slaughter houses. In southern California, the whey content of dairy wastes reaching sewage ponds through the sewer system caused them to perform poorly, as indicated by the low concentrations of dissolved oxygen and desirable algae as well as the presence of dissolved sulfides and hydrogen sulfide odors (23). In Australia, it was found possible to treat food cannery wastes in large anaerobic lagoons after mixing them with sewage plant effluent and digested sludge or digester supernatant. The wastewater was then passed through an aerobic pond or oxidation ditch. Vigorous algal growth was observed to persist at all times in all the lagoons, both anaerobic and aerobic (24).

In northwestern United States and Pennsylvania, wastes from sugar beet factories have sometimes caused algae to disappear from sewage ponds and to be replaced by sulfur bacteria, which turned the water pinkish-red. In central California, the wastes from a slaughter house caused the water of a sewage pond to become almost free of algae and a blood-red color to form on the surface due to the presence of sulfur bacteria.

The algal population in sewage ponds may also be radically reduced in quantity by small aquatic animals, particularly *Daphnia,* which can develop in large numbers and consume the algae. This has been observed in ponds in southern California. In one case the *Daphnia* were purple and were so numerous as to color the surface of the water. The life cycle of these aquatic animals is relatively short, and they generally disappear in 2 to 4 weeks.

Sometimes it is desired that the final pond containing stabilized sewage be a clarified polishing pond relatively free of algae. This has been accomplished by introducing the floating green plant *Lemna* which shades the water below. The shaded water causes algae to die out and to decompose rapidly with the aid of bacteria. This results in encouragement of crustacea especially *Daphnia* which feed on the saprobic bacteria. *Daphnia* cultures may have to be introduced to quicken the process. The *Lemna* — bacterium — *Daphnia* procedure clarifies the stabilized sewage pond, frees it of algae and total bacteria, and leaves microscopically clear water. The *Daphnia* are first-class food for fish and can be so utilized either in a final pond or in the stream that receives the effluent (25).

It may be concluded that the application of biological principles should make it possible to improve the efficiency of waste treatment oxidation-stabilization ponds.

REFERENCES

1. Nutrient assimilation by algae in waste stabilization ponds. C. M. Palmer. Proc. Ind. Acad. Sci. for 1966, 76:204-209. 1967.
2. Waste stabilization pond study, Lebanon, Ohio. W. B. Horning II, R. Porges, H. F. Clarke, and Wm. B. Cooke. Pub. Hlth. Serv. Publ. No. 999-WP-16:1-48. 1964.
3. An evaluation of stabilization pond literature. G. P. Fitzgerald and G. A. Rohlich. Sew. and Indus. Wastes 30:1213-1224. 1958.
4. Algae in waste treatment. W. J. Oswald, H. B. Gotaas, C. G. Golueke, and W. R. Kellen. Sew. and Indus. Wastes 29:437-457. 1957.
5. Depth and loading rates of oxidation ponds. D. A. Mills. Water and Sew. Wks. 108:343-346. 1961.
6. Waste stabilization lagoons in Missouri. J. K. Smith. Proc. Symposium on Waste Stabilization Lagoons. Kansas City, Mo., Aug. 1960. U.S. Pub. Hlth. Serv. 157-161. 1960.
7. Performance of large sewage lagoons at Melbourne, Australia. C. D. Parker, H. L. Jones, and N. C. Green. Sew. and Indus. Wastes 31:133-152. 1959.
8. Stabilization pond studies in Wisconsin. K. M. MacKenthun and C. D. McNabb. Jour. Water Pol. Contr. Fed. 33:1234-1251. 1961.
9. Studies of sewage lagoons. J. Myers. Pub. Wks. 79(12):25-27. Dec. 1948.
10. Chromatographic assay of extracellular products of algal metabolism. R. C. Merz, R. G. Zehnpfennig, and J. R. Klima. Jour. Water Pol. Contr. Fed. 34:103-115. 1962.
11. General features of algal growth in sewage oxidation ponds. M. B. Allen. Cal. State Water Pollution Control Board. Publ. No. 13. p. 1-47. 1955.
12. Removal of sewage nutrients by algae. R. H. Bogan. Pub. Hlth. Repts. 76:301-308. 1961.
13. Nutrient removal from sewage effluents by algal activity. J. Hemens and G. J. Stanoler. Advances in Water Pollution Research. Fourth Internat. Conf. on Water Pol. Res., Prague. Pergamon Press. p. 701-711. 1969.
14. Experimental lagooning of raw sewage at Fayette, Missouri. J. K. Neel, J. H. McDermott, and C. A. Monday, Jr. Jour. Water Pol. Contr. Fed. 33:603-641. 1961.

15. Algae in American sewage stabilization ponds. C. M. Palmer. Rev. Microbiol. (Sao Paulo, Brazil) 5(4):75-80. 1974 (Released Aug. 1975).
16. Algal records for three Indiana sewage stabilization ponds. C. M. Palmer. Proc. Indiana Acad. Sci. for 1968, 78:139-145. 1969.
17. Some observations on the action of algae on sewage in ponds. H. T. Clausen. Jour. and Proc. Institute of Sew. Purif. Part. 3:345-348. 1959.
18. A systematic study of the algae of sewage oxidation ponds. P. C. Silva and G. F. Papenfuss. Cal. State Water Pol. Control Bd. Publ. No. 7:1-35. 1953.
19. Ecophenes of *Schizothrix calcicola (Oscillatoriacea)*. F. Drouet. Proc. Acad. Nat. Sci. Phila. 115:261-281. 1963.
20. Guide to operators of raw sewage stabilization ponds. In National Institute for Water Res. Council for Scientific and Indus. Res. Rept. of Director for 1962. CSIR Special Rept. No. WAT. 27: Pretoria, South Africa. 76 p. June 1963.
21. Algal community structure in artificial ponds subjected to continuous organic enrichment. M. S. Ewing. Thesis, Oklahoma St. Univ., Grad. Col. 41 p. July 1966.
22. Rapid growth of sewage lagoon *Chlamydomonas* with acetate. R. W. Eppley and F. M. Maciasa. Physiologia Plantarum 15:72-79. 1962.
23. Effect of whey wastes on stabilization ponds. T. E. Maloney, H. F. Ludwig, J. A. Harmon, and L. McClintock. Jour. Water Pol. Contr. Fed. 32:1283-1299. 1960.
24. Food cannery waste treatment by lagoons and ditches at Shepparton, Victoria, Australia. C. D. Parker. Proc. 91st Indus. Waste Conf. May 1966. Pt. 1. Eng. Bull. Purdue Union 50 (No. 1), Eng. Extension Ser. No. 121:284-301. 1966.
25. Two experiments in the biological clarification of stabilization-pond effluents. S. Ehrlich. Hydrobiologia 27:70-80. 1966.

TABLE 13. ALGAL GENERA IN AMERICAN SEWAGE PONDS

Achnanthes
Actinastrum
Agmenellum
Anabaena
Anabaenopsis
Anacystis
Ankistrodesmus
Aphanizomenon
Apiococcus
Arthrospira
Calothrix
Carteria
Characium
Chlamydomonas
Chlorella
Chlorococcum
Chlorogonium
Chodatella
Chromulina
Chroomonas
Chrysamoeba
Cladophora
Closteridium
Closteriopsis
Closterium
Coccomonas
Coelastrum
Cosmarium
Crucigenia
Cryptomonas
Cyanomonas
Cyclotella
Cymatopleura
Cymbella
Dermocarpa
Desmidium
Diacanthos
Dictyosphaerium
Dinobryon
Dispora
Dunaliella
Elakatothrix
Enteromorpha
Epithemia
Eudorina
Euglena
Fragilaria
Frustulia
Glenodinium
Gloeocystis
Golenkinia
Gomphonema
Gomphosphaeria
Gonium
Gymnodinium
Haematococcus
Hantzschia
Hemidinium
Johannesbaptistia
Kirchneriella
Lepocinclis
Lyngbya
Mallomonas
Massartia
Micractinium
Microspora
Nannochloris
Navicula
Nitzschia
Ochromonas
Oedogonium
Oocystis
Oscillatoria
Ourococcus
Palmella
Palmellococcus
Pandorina
Pediastrum
Pedinopera
Phacus
Phormidium
Pinnularia
Planktosphaeria
Pleodorina
Pleurogaster
Polyedriopsis
Pteromonas
Pyrobotrys
Raphidiopsis
Rhodomonas
Scenedesmus
Schizothrix
Schroederia
Selenastrum
Sphaerellopsis
Sphaerocystis
Spirogyra
Spirulina
Staurastrum
Stauroneis
Stichococcus
Stigeoclonium
Surirella
Synedra
Tetradesmus
Tetraedron
Tetrastrum
Trachelomonas
Ulothrix
Uroglenopsis
Vacuolaria
Zoochlorella
Zygnema

TABLE 14. ALGAE MOST ABUNDANT AND WIDESPREAD IN SEWAGE PONDS

Rank	Genus	Score*
1	Chlorella	51
2	Ankistrodesmus	49
3	Scenedesmus	49
4	Euglena	48
5	Chlamydomonas	47
6	Oscillatoria	46
7	Micractinium	39
8	Golenkinia	37
9	Anacystis	34
10	Oocystis	34
11	Chodatella	33
12	Nitzschia	32
13	Nannochloris	31
14	Planktosphaeria	29
15	Pandorina	29
16	Pteromonas	28
17	Closteridium	28
18	Cryptomonas	28
19	Chlorococcum	28
20	Schizothrix	28
21	Cyclotella	27
22	Phacus	27
23	Schroederia	25
24	Trachelomonas	25
25	Actinastrum	25

*Note: Score was determined by adding together the highest sampling date abundance figure, the number of states for the genus, and the number of states where abundance figure was 5 or above. Genera with similar scores were ranked according to the first item.

TABLE 15. VARIOUS CONDITIONS OF SEWAGE OXIDATION-STABILIZATION PONDS
(Adapted with many modifications from CSIR Special Report (19))

	Observations	Pond conditions	Dominant algae	Mid-afternoon		BOD$_5$ mg/l		Total nitrogen reduction
				pH	DO (mg/1)	at inlet	at outlet	
Primary pond	Green to depth of 2′. No smell from pond or effluent sample.	Aerobic	Algae abundant: Scenedesmus, etc.	8.5	10+	50	25	Good
	Green to depth of 6″. Blackfish tint below 6″. Sulfide odor slight.	Aerobic above Anaerobic below	Algae common Chlamydomonas	7.5	4	75	45	Poor
	Grey, black or clear black. Sulfide odor strong. Surface smooth and oily.	Anaerobic	Algae scarce: Chlamydomonas, Euglena	7.0	0	80	70	Poor
Secondary and subsequent ponds	Green color. Surface easily rippled.	Aerobic	Algae abundant: Ankistrodesmus, Scenedesmus, Golenkinia, etc.	10±	30±	45±	15	Good
	Light Green. Surface easily rippled.	Aerobic	Algae common: Scenedesmus, Nitzschia, Chlorella, etc.	9	20	45±	20	Good
	Greenish or brownish tint. Clear.	Aerobic	Algae moderate: Cryptomonas, Chlamydomonas, etc.	8	6±	15±	10	Poor
	Black. Clear.	Anaerobic or not functioning	Algae scarce: Chlamydomonas, Euglena, Oscillatoria	7±	0	100±	70	Poor

CHAPTER XIII

TASTE AND ODOR ALGAE

One of the requirements in the production of potable water for communities is that the product be free of obnoxious tastes and odors. If such problems exist, they are generally attributable to the algae present in the raw water supply. In a comprehensive study made of algae in the central Missouri River, the time when taste and odor difficulties occurred was recorded at treatment plants of cities and towns that used the river as their source of water (1). It was found that practically all of the taste and odor occurrences coincided with the presence of algal blooms and that the few exceptions noted came during declines of dense algal growths. It is evident that, for the central Missouri River area as well as for many other parts of the country, algae are involved either directly or indirectly in causing taste and odor problems in water supplies.

A nationwide survey conducted in 1957 indicated that water works officials considered algae to be the most frequent causes of tastes and odors in water supplies, and decaying vegetation to be second in importance (2). The decay or decomposition is brought about by the activity of fungi and bacteria, including the actinomycetes. A considerable proportion of all decaying vegetation is often composed of dead algal cells. The odors that are produced as a result of the activities of fungi and bacteria may be either from the intermediate products formed during the decomposition or from special substances that are synthesized within the cells of the microorganisms. The latter appears to be true in the case of actinomycetes.

A few algae are known to produce specific distinctive tastes and odors, while a larger number of others are associated with tastes and odors that vary in type according to local conditions. Certain diatoms, blue-green algae, and pigmented flagellates are the principal offenders, but green algae, including desmids, may also be involved. Forty species representative of the more important taste and odor algae are listed alphabetically under their respective groups in table 16 and eighteen are illustrated on plate VII. Other genera and species must also be considered as potential offenders, and many of these are included in table 17, which lists the odor, taste, and tongue effects of more than 50 genera of algae. Most of the reports dealing with specific instances in which algae were regarded as having been the cause of taste and odor problems did not give the species name of the particular forms involved. In the following discussion, therefore, reference is made to the genera rather than the species of algae.

TYPICAL ODORS FROM ALGAE

Some algae produce an aromatic odor resembling that given off by a particular flower or vegetable, e.g., geranium, nasturtium, violet, muskmelon, and cucumber. In some cases it is described as an attractive, spicy odor, but in others it may be very objectionable, for example, a skunk or garlic odor. Some pigmented flagellates and diatoms produce the aromatic odors when these organisms are present in small numbers in the water.

A fishy odor is often produced by the same algae that are responsible for the aromatic odors, but the organisms generally are present in much larger numbers. More specific terms that have been used to describe the fishy odors are clam-shell, cod-liver oil, sea weed, Irish moss, rockweed, and salt marsh. The differences between these are probably insignificant in water supply studies.

A grassy odor is the most common one produced by green algae and generally is apparent only when the organisms are present in large numbers. Certain blue-green algae and occasionally diatoms and pigmented flagellates are said to cause this odor.

The fourth type of odor is one described as being musty or earthy. The latter is commonly associated with actinomycetes (3,4) and with a few algae; it can vary from mild to decidedly pungent. The earthy odor of soil is also probably caused by the presence of actinomycetes. The musty odor frequently given off by water is associated with the presence of certain blue-green algae and a few other forms, especially the diatom *Synedra*. It has also been described as being potato bin and moldy. Some waters have been reported as having weedy, swampy, marshy, peaty, straw-like, and woody odors, and these are possibly modifications or combinations of the grassy and musty odors.

A septic odor has been associated frequently with the presence of large accumulations of blue-green algae and occasionally of the green algae, *Hydrodictyon* and *Cladophora*. Other names applied to this type of odor are pigpen, foul, objectionable, vile, fermentation, and putrefactive (5). As these terms suggest, it is produced when masses of algae decompose, especially when a lack of sufficient oxygen permits the formation of odoriferous intermediate products from the algal proteins.

Chlorophenolic, iodoform, or medicinal odors may be produced by the action of chlorine on the products of certain algae, but somewhat similar odors may be present in water at other times because of industrial wastes.

MEASUREMENT OF ODORS

The threshold odor test is commonly employed to measure odors in water. The threshold odors caused by algae tend in some areas to be comparatively low (1 to 14), but in other areas they frequently go up to 30 or 40 and occasionally exceed 90. Algal odors are generally objectionable, however, even when the threshold odor number is low. For satisfactory treatment, the threshold odor usually has to be reduced to 5 or less. However, each water supply and often each odor outbreak must be judged independently in determining the threshold number below which the water is considered palatable.

In some plants the treatment is instituted as soon as any algae that can cause taste and odor problems increase to a predetermined number of areal standard units per ml. The number varies according to the particular kind of alga involved: for *Asterionella* and *Synedra* it may be 3,000; *Tabellaria*, 2,500; *Aphanizomenon*, 1,000; *Anabaena*, 600; *Dinobryon*, 500; *Cryptomonas*, *Synura*, and *Uroglenopsis*, 200; and *Chlamydomonas*, 10 (7,8).

Tastes produced by algae are seldom separated from and are often confused with odor. Sweet and bitter are the adjectives generally recorded, and it is quite possible that a sour taste may be present whenever the odor is acid or is of the putrefactive, septic, or pigpen type. A salty taste apparently has never been associated with the fishy, clam-shell, salt marsh, rockweed, Irish moss, or seaweed-like odors.

The tongue can also detect a sensation that might be listed as "feel" or "touch." Included here would be a slick or oily feel as well as a metallic, dry, or an astringent sensation. Odor, taste, and feel, as associated with each algal genus are given in table 17. The word "flavor" could be used as an inclusive term embracing taste, odor, and touch or feel (9).

PRINCIPAL ODOR-PRODUCING ALGAE

Synura is one of the more potent algae in giving water an odor which is often described as resembling that of a ripe cucumber or muskmelon. A comparatively few colonies per milliliter may be sufficient to cause a very perceptible odor. This organism also produces a bitter taste in water and leaves a persistent dry metallic sensation on the tongue. When present in large numbers, this flagellate as well as others may develop a fishy odor. In Massachusetts, for example, *Dinobryon*, *Uroglenopsis* (fig. 60), and the armored flagellate *Peridinium* produced a strong fishy odor in a large reservoir holding over 600 million gal water. These forms developed in February under a 16-inch layer of ice (10). There is some evidence that *Uroglenopsis* is stimulated to rapid growth following an abundant growth of other algae. Among other flagellate algae which produce tastes and odors are *Euglena*, *Gonium*, *Chlamydomonas*, and *Cryptomonas* (fig. 60).

In California one of the worst offenders was the armored flagellate *Ceratiums* which produces a fishy to pronounced septic odor. The organism is capable of very rapid multiplication during any season (11).

Dinobryon develops in the southern end of Lake Michigan almost every June and July in numbers sufficient to impart a pronounced fishy odor to the water. As many as 700 areal standard units/ml of this alga have been reported, and it has represented at times up to 47 percent of the total algal count. Even though its odor is readily adsorbed by activated carbon, it is estimated that one treatment plant required over $70,000 worth of the carbon to control the odor for a period of 2 months (12). *Dinobryon* and other taste and odor algae may develop as pulses which follow one another in a lake or reservoir (fig. 61).

Asterionella is considered one of the worst offenders among the diatoms because its geranium-like odor changes to a fishy smell when the alga is present in large numbers. *Tabellaria* produces a similar effect, while *Synedra* has an earthy to musty odor, and *Stephanodiscus* imparts a vegetable to oily taste but has very little odor.

Certain blue-green algae develop very foul, pigpen odors in water. Three of these algae, illustrated on plate VII are *Anabaena*, *Anacystis* (formerly known as *Microcystis*, *Polycystis*, and *Clathrocystis*), and *Aphanizomenon*. All of these are capable of collecting in large masses sufficient to form water blooms. The foul odor undoubtedly develops from products of decomposition as the algae begin to die off in large numbers. These blue-green algae, together with others such as *Gomphosphaeria* (which now includes *Coelosphaerium*), *Cylindrospermum*, and *Rivularia* have a natural odor which is commonly described as grassy. This often changes to the odor of nasturtium stems, probably as a result of oxidation.

On several occasions in July, *Anabaena* in Chicago's raw water gave an unpleasant, persistent odor even when present in very small numbers, and large doses of activated carbon were required to remove the odor (13).

There were 48 genera detected in the raw lake water supply of Celina, Ohio, in one year. Almost 50 percent of them were taste and odor producing types. The worst offenders were *Anacystis (Microcystis)*, *Scenedesmus*, *Synedra*, *Gomphosphaeria*, *Coelospherium*, *Dictyosphaerium*, and *Tabellaria*. The threshold odor number of the raw water reached as high as 24. The installation of an intake structure designed to allow water to be drawn from various levels in the lake, facilities for use of algicides and other chemicals, and the addition of a presedimentation basin were recommended for future control of taste and odor algae (14).

Green algae are less often associated with tastes and odors in water. In fact, their growth may help to keep in check the blue-green algae and the diatoms. However, *Hydrodictyon* (water net), the desmid *Staurastrum*, and the large massive stone-worts *Nitella* and *Chara* may offend rather than help in this biological competition between types. *Distyosphaerium* is regarded as one of the worst offenders among the green algae. It gives off a fishy as

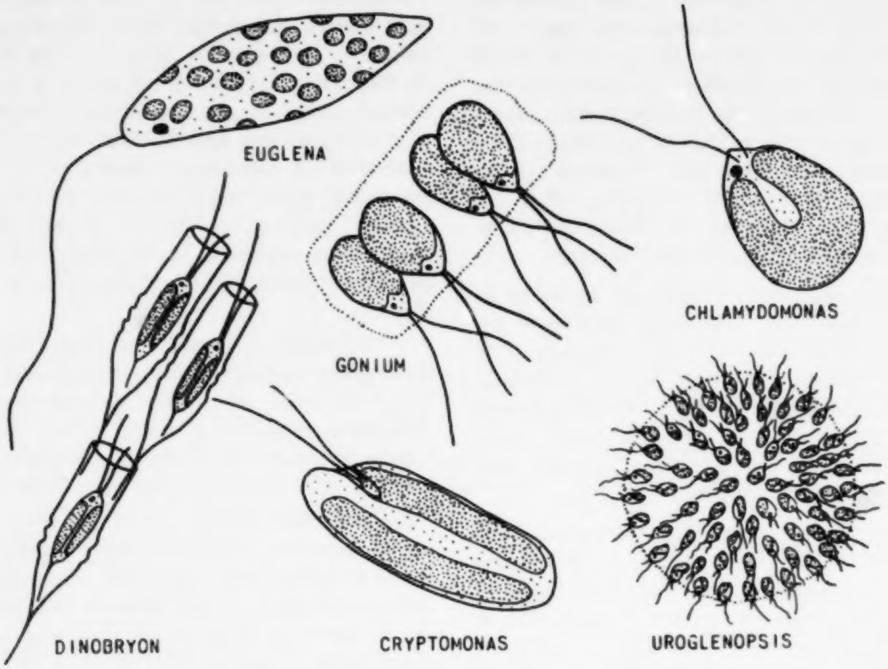

EUGLENA
CHLAMYDOMONAS
GONIUM
DINOBRYON
CRYPTOMONAS
UROGLENOPSIS

Figure 60.—Some flagellate algae producing tastes and odors.

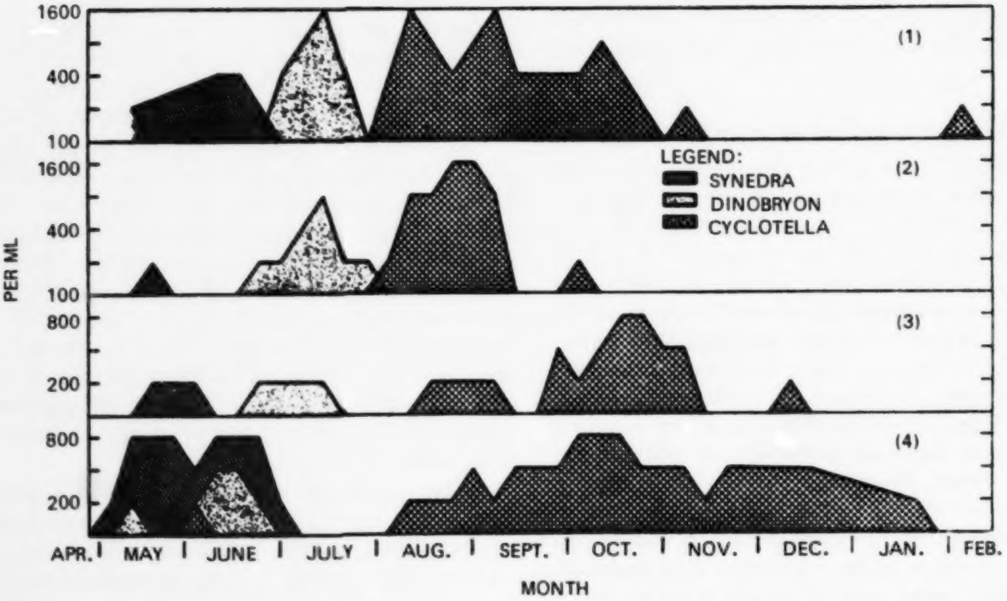


Figure 61.—Pulses, over a four year period, of three taste and odor algae in a water supply reservoir.

well as a grassy to nasturtium odor (15). Some of the swimming green algae which are listed with the flagellates, including *Volvox, Pandorina,* and *Chlamydomonas,* are able to produce fishy odors.

Research was conducted at the Robert A. Taft Sanitary Engineering Center on taste and odor algae. Suspected forms were obtained in pure growth cultures (16), and chemical analyses were made of their products and of various organic materials on water which had odor (17,18). Additional research was directed toward the finding of algicides which were sufficiently selective to destroy certain taste and odor algae without simultaneously being wasted on non-offending types (19). The relationship of actinomycetes to earthy odors in water was also studied (20-22).

The following statement by Laughlin (23) is an expression of the emphasis which the control of taste and odor problems must be given in modern programs for water treatment: "It is one of the basic duties and responsibilities of the water purification plant operator to furnish his public with palatable water 24 hours a day. The presence of any objectionable odor may cause the consumer to go to a more palatable but unsafe water supply. Therefore, the importance of producing a palatable water supply cannot be overemphasized."

REFERENCES

1. Central Missouri River water quality investigation for 1955. U.S. Dept. Health, Education and Welfare, Public Health Service, Water Supply and Water Pollution Control Section, Region 6, Kansas City, Mo., 50 p. (Mimeographed). 1956.
2. Control of odor and taste in water supplies. E. A. Sigworth. Jour. Amer. Water Wks. Assn. 49:1507-1521. 1957.
3. The role of actinomycetes in producing earthy tastes and smells in potable water. B. A. Adams. Dept. of Public Wks., Roads and Transport Congress. Paper No. 4. London, England. 1933.
4. Actinomycetes may cause tastes and odors in water supplies. J. K. Silvey and A. W. Roach. Public Wks. Mag. 87:103-106, 210, 212. 1956.
5. The microscopy of drinking water. Ed. 4. G. C. Whipple, G. M. Fair, and M. C. Whipple. J. Wiley and Sons, N.Y., 586 p. With 19 color plates. 1948.
6. Standard methods for the examination of water, sewage and industrial wastes. Ed. 10. Amer. Public Health Assn., N.Y., 522 p. 1955.
7. Tastes and odor control. G. E. Symons. Water and Sewage Wks. 1903:307-310, 348-355. 1956.
8. The effects of algae on water quality. D. F. Jackson. Proc. 1st Amer. Water Qual. Res. Symp., N.Y. State Dept. Health and N.Y. Water Pol. Assn., Albany, N.Y., p. 2-23. 1964.
9. The relation of taste and odor to flavor. C. W. Aman. Taste and Odor Control Jour. 21 (No. 10):1-4. 1955.
10. Treating algae under the ice at Westfield, Mass. E. A. Snow and A. Iantosca. Jour. New England Water Wks. Assn. 66:47-54. 1952.
11. Microscopic organisms in reservoirs. C. A. Cofoid. Jour. Amer. Water Wks. Assn. 10:183-191. 1923.
12. Fishy odor in water caused by *Dinobryon*. J. R. Baylis. Pure Water, Chicago, Ill., South District Filtration Plant, 3:128-150. 1951.
13. Operation of the South District filtration plant. A. F. Mrva. Pure Water, Chicago Bur. of Waters 17:51-71. 1965.
14. Taste and odor removal at Celina. C. Bauer. Jour. Amer. Water Wks. Assn. 58:113-118. 1966.
15. Review of microorganisms in water supplies. S. O. Swartz. Jour. New England Water Wks. Assn. 69:217-227. 1955.
16. The use of algal cultures in experiments concerned with water supply problems. C. M. Palmer and T. E. Maloney. Butler Univ. Bot. Stud. 11:87-90. 1953.
17. Drinking water taste and odor correlation with organic chemical content. F. M. Middleton, G. Wallace, and A. A. Rosen. Indust. Eng. Chem. 48:268-274. 1956.
18. Identification of odor producing substances elaborated by algae. T. E. Maloney. Public Works Mag. 89:99-100. 1958.
19. Evaluation of new algicides for water supply purposes. C. M. Palmer. Jour. Amer. Water Wks. Assn. 48:1133-1137. 1956.
20. Identification of odors produced by actinomycetes. A. H. Romano. Public Works Mag. 89:100-101. 1958.
21. A method for the isolation and enumeration of actinomycetes related to water supplies. R. S. Safferman and M. E. Morris. Robt. A. Taft San. Eng. Center, Tech. Rept. W62-10. 15 p. 1962.
22. Studies on actinomycetes and their odors. A. H. Romano and R. S. Safferman. Jour. Amer. Water Wks. Assn. 55:169-176. 1963.
23. Palatable level with the threshold odor test. H. F. Laughlin. Taste and Odor Control Jour. 20 (No. 8):1-4. 1954.

TABLE 16. TASTE AND ODOR ALGAE, REPRESENTATIVE SPECIES

Group and algae	Plate
Blue-Green Algae (Myxophyceae):	
Anabaena circinalis	
Anabaena planctonica	VII
Anacystis cyanea	VII
Aphanizomenon flos-aquae	VII
Cylindrospermum musicola	
Gomphosphaeria lacustris, kuetzingianum type	VII
Oscillatoria curviceps	
Rivularia haematites	
Symploca muscorum	
Green Algae (nonmotile Chlorophyceae, etc.)	
Chara vulgaris	
Chladophora insignis	
Cosmarium partianum	
Dictyosphaerium ehrenbergianum	
Gloeocystis planctonica	
Hydrodictyon reticulatum	
Nitella gracilis	VII
Pediastrum tetras	VII
Scenedesmus abundans	
Spirogyra majuscula	
Staurastrum paradoxum	VII
Diatoms (Bacillariuphyceae):	
Asterionella gracillima	VII
Cyclotella comta	
Diatoma vulgare	VIII
Fragilaria construens	
Stephanodiscus niagarae	
Synedra ulna	VII
Tabellaria fenestrata	VII
Flagellates (Chrysophyceae, Euglenophyceae, etc.):	
Ceratium hirundinella	VII
Chlamydomonas globosa	
Chrysosphaerella longispina	
Cryptomonas erosa	
Dinobryon divergens	VII
Euglena sanguinea	
Glenodinium palustre	
Mallomonas caudata	VII
Pandorina morum	VII
Peridinium cinctum	VII
Synura uvella	VII
Uroglenopsis americana	VII
Volvox aureus	VII

TABLE 17. ODORS, TASTES, AND TONGUE SENSATIONS ASSOCIATED WITH ALGAE IN WATER

Algal genus	Algal group	Odor when algae are—		Taste	Tongue sensation
		Moderate	Abundant		
Actinastrum	Green		Grassy, Musty		
Anabaena	Blue-green	Grassy, nasturtium, musty.	Septic		
Anabaenopsis	Blue-green		Grassy		
Anacystis	Blue-green	Grassy	Septic	Sweet	
Aphanizomenon	Blue-green	Grassy, nasturtium, musty.	Septic	Sweet	Dry.
Asterionella	Diatom	Geranium, spicy	Fishy		
Ceratium	Flagellate	Fishy	Septic	Bitter	
Chara	Green	Skunk, garlic	Spoiled, garlic		
Chlamydomonas	Flagellate	Musty, grassy	Fishy, septic	Sweet	Slick.
Chlorella	Green		Musty		
Chrysosphaerella	Flagellate		Fishy		
Cladophora	Green		Septic		
(Clathrocystis)	See Anacystis.				
Closterium	Green		Grassy		
(Coelosphaerium)	See Gomphosphaeria.				
Cosmarium	Green		Grassy		
Cryptomonas	Flagellate	Violet	Violet	Sweet	
Cyclotella	Diatom	Geranium	Fishy		
Cylindrospermum	Blue-green	Grassy	Septic		
Diatoma	Diatom		Aromatic		
Dictyosphaerium	Green	Grassy, nasturtium	Fishy		
Dinobryon	Flagellate	Violet	Fishy		Slick.
Eudorina	Flagellate		Fishy		
Euglena	Flagellate		Fishy	Sweet	
Fragilaria	Diatom	Geranium	Musty		
Glenodinium	Flagellate		Fishy		Slick.
(Gloeocapsa)	See Anacystis.				
Gloeocystis	Green		Septic		
Gloeotrichia	Blue-green		Grassy		
Gomphosphaeria	Blue-green	Grassy	Grassy	Sweet	
Gonium	Flagellate		Fishy		
Hydrodictyon	Green		Septic		
Mallomonas	Flagellate	Violet	Fishy		
Melosira	Diatom	Geranium	Musty		Slick.
Meridion	Diatom		Spicy		
(Microcystis)	See Anacystis.				
Nitella	Green	Grassy	Grassy, septic	Bitter	
Nostoc	Blue-green	Musty	Septic		
Oscillatoria	Blue-green	Grassy	Musty, spicy		
Pandorina	Flagellate		Fishy		
Pediastrum	Green		Grassy		
Peridinium	Flagellate	Cucumber	Fishy		
Pleurosigma	Diatom		Fishy		
Rivularia	Blue-green	Grassy	Musty		
Scenedesmus	Green		Grassy		
Spirogyra	Green		Grassy		
Staurastrum	Green		Grassy		
Stephanodiscus	Diatom	Geranium	Fishy		Slick.
Symploca	Blue-green		Musty		
Synedra	Diatom	Grassy	Musty		Slick.
Synura	Flagellate	Cucumber, muskmelon, spicy.	Fishy	Bitter	Dry, metallic, slick.
Tabellaria	Diatom	Geranium	Fishy		
Tribonema	Green		Fishy		
(Uroglena)	See Uroglenopsis.				
Uroglenopsis	Flagellate	Cucumber	Fishy		Slick.
Ulothrix	Green		Grassy		
Volvox	Flagellate	Fishy	Fishy		

CHAPTER XIV

FILTER AND SCREEN CLOGGING ALGAE

As water passes through a sand filter in a treatment plant, the spaces between the grains of sand become filled with colloidal and solid particles which had been dispersed in the water. If the raw water comes from a surface supply such as a reservoir, lake, or stream, the algae which are invariably present will be well represented in the material collected by the sand filter and are frequently the primary causes for the clogging of the filter.

In most places the algae and other particulate materials are sufficiently numerous throughout most of the year to require that the water be treated by coagulation and sedimentation previous to filtration through sand. Without this preliminary treatment, the filter would clog so rapidly that it would be uneconomical to use, except when relatively clear water is available. Certain plants in California and in Canada have been using a rapid sand filter without prior coagulation, at least during portions of the year (1).

Efficient coagulation and sedimentation can remove up to 90 or 95 percent of the algae from the water, but those algae remaining may still cause a gradual or even rapid loss of head in the sand filter. The clogged filter must then be taken out of service and cleaned or backwashed. Normal filter runs are from 30 to 100 hr before cleaning is required, but the presence of algae can reduce the time to less than 10 hr (2). In extreme cases the clogging may recur so frequently that the amount of water required to backwash the filter is greater than the volume of filtered water which reaches the distribution system. Thus the presence of algae can slow up the process of water treatment and add materially to its cost.

CLOGGING PROCESSES

Both the slow and rapid sand filters may become clogged with algae, but in the former the algae and other aquatic microorganisms may play a useful part in the treatment process. They form a loose, slimy layer over the surface of the sand and act as a filter. The algae in this layer release oxygen during photosynthesis, and the oxygen in turn is utilized by aerobic saprophytic bacteria, fungi, and protozoa which establish themselves in and on the filter. This permits the decomposition or stabilization of the organic material that was present in the raw water. On the other hand, diatoms, which have rigid walls, may do more harm than good because they speed up the clogging of the filter, but it is possible to use slow sand filters when diatoms have put rapid filters out of commission (3). The water that has passed through a slow sand filter is relatively free of bacteria, algae, other organisms, and organic matter.

It is not yet fully understood why certain algae are more effective than others in reducing the movement of water through the filters, but an ability to develop in large numbers is certainly essential. A rigid wall such as that found in the diatoms, the copious mucilaginous material around the cells, as in the case of *Palmella*, and the tendency to form flakes or a network of strands, as in *Fragilaria* and *Tribonema*, are other factors.

Diatoms are present during all seasons of the year and are by far the most important group of organisms which clog filters. The most serious offenders are *Asterionella*, *Fragilaria*, *Tabellaria*, and *Synedra*. Other diatoms that may occasionally cause this trouble include *Navicula*, *Cyclotella*, *Diatoma*, and *Cymbella*, all of which are illustrated on plate VIII. The rigid cell wall of diatoms is composed principally of silica and is not subject to decomposition. Therefore, even though the diatoms may die off rapidly on the surface of the filter, their silica walls remain and plug the pores in the sand.

In England a relatively pure growth of *Fragilaria* developed in a reservoir to the extent that it was necessary to remove huge quantities of this diatom at the water treatment plant. Counts of another filter clogging diatom, *Asterionella*, indicated that the organism had reached a density as high as 20,000/ml (4).

In Chicago, when the water to be filtered contained approximately 700 microorganisms/ml, principally *Tabellaria* and *Fragilaria*, the filter runs lasted only 4.5 hr. Three days later, when the count was down to approximately 100/ml, the filter run increased to 41 hr (5).

Tabellaria is the organism causing most short filter runs. It is likely to be present in considerable numbers all year long except during January and February. *Tabellaria*, which is a free-floating diatom, is most abundant in water having little turbidity, and when coagulated with aluminum sulfate, the coagulated material does not settle rapidly. The cells are generally united in zigzag chains by gelatinous cushions at the corners. The zigzag arrangement and the gelatinous cushions, which can be stretched, make the length of the chain flexible, and this helps to prevent it from breaking on the filter surface. These chains, therefore, may be more effective than long filamentous algae in producing a clogging membrane on the top of the filter. At Chicago there have been a dozen or more periods of short filter runs within 1 year, and some of the periods lasted for two or three weeks (6). In Washington, D.C., filter runs were reduced from an average of 50 hr to less than 1 hr due to the sudden influx of the diatom *Synedra*, which reached a concentration in the raw water of 4,800 cells/ml (7).

The filter clogging blue-green algae are represented on plate VIII by *Anacystis (Chroococcus* type), *Rivularia, Anabaena*, and three species of *Oscillatoria*. *Anabaena* is known to have caused filter trouble in Illinois and Minnesota while *Oscillatoria* has been one of the offenders in Switzerland. *Dinobryon* and *Trachelomonas* are pigmented flagellates, the former being common in the Great Lakes and in the soft waters of the eastern United States. A treatment plant in England experienced phenomenally high counts of *Ceratium hirundinella* during the summer. The counts reached almost 750,000 cells/ml and created major coagulation and filtration problems. At one time nearly 40 percent of the treated water was required to backwash the filters (8). *Chlorella, Palmella, Spirogyra*, and the desmid, *Closterium*, are green algae, while *Tribonema* is a yellow-green filament. *Chlorella* is the alga which has given trouble by clogging filters made of glass wool. In addition, it grows on the inner surfaces of glass bottles in water coolers and in water lines constructed of plastic tubing, when these have been exposed to light. In the tropics and the warm temperate zone, the filamentous green algae often clog sand filters.

Forty-five of the more important filter clogging algae are listed alphabetically under their major groups in table 18. Twenty-two are illustrated in color on plate VIII, and a few of the remaining forms are to be found on the other plates, as indicated in the table.

Most of the microscopic organisms present in water that is sand filtered generally will be caught in the top 0.5 in. of the sand, particularly when the organisms are abundant in the water. A few of the organisms will penetrate deeper into the filter bed, while others disintegrate quickly as they come in contact with the sand. The longer the filter run, the greater the percentage of organisms that will penetrate below the top 0.5 in.

In Chicago a study was made of the numbers of certain diatoms that were caught on the surface of rapid sand filters. The samples were collected immediately before the filters were backwashed. During 1 year of this study, *Tabellaria* ranged in numbers from 496,000 to 936,000 sq in. of filter surface in April, and from 1,824,000 to 8,016,000 in November. In contrast, the range for *Melosira* was from 784,000 to 2,624,000 in April, and only 16,000 to 416,000 in November (9).

At the water intake cribs of Chicago's water system, a tubular branching green alga, *Dichotomosiphon tuberosus*, was caught on 33 of the fish-collecting screens in sufficient amount to clog them. Compressed air hoses were used to separate the algal growth from the screens. The alga resembles *Vaucheria* but has constrictions at the base of each tubular branch. It normally develops in deep water and was evidently brought into the water system after breaking away from its original location. It has caused this problem in Chicago at least three times in a period of 8 years (10).

The relationships of algae to sand filters involve also the problem caused by the passage of certain algae through both rapid and slow filters and into the treated water. A number of the same algae that can clog filters have at other times been able to penetrate them. Algae that have passed through rapid filters include *Synedra* and *Oscillatoria* and through slow filters, *Chlamydomonas, Euglena, Navicula, Nitzschia, Phacus*, and *Trachelomonas* (11). The ease with which the algae penetrate depends upon several factors, the principal ones being the rate of flow, the grade of sand used, and the type of organism. Very minute algae and flagellates penetrate with greater facility than other types. When the penetration is slow, it may be a few hours before the algae reach the underdrains. Frequent backwashing, even when the filter is not clogged, tends to remove the algae and reduce the number that reach the filtered water.

REFERENCES

1. The effects of algae in water supplies. D. H. Matheson. International Water Supply Assn., General Rept. to 2d Congress, Paris, France, 82 p. 1952.
2. Algae control at Danbury, Connecticut. E. A. Tarlton. Jour. New England Water Wks. Assn. 63:165-174. 1949.
3. Interesting experiences with microorganisms in the Washington water supply. G. E. Harrington. Proc. 9th Ann. Conf. Md.-Del. Water and Sewerage Assn., p. 74-99. 1935.
4. Freshwater biology and water supply in Britain. W. H. Pearsall, A. C. Gardiner, and F. Greenshields. Freshwater Biolog. Assn. of the British Empire. Publ. No. 11, 90 p. 1946.
5. Effect of microorganisms on lengths of filter runs. J. R. Baylis. Water Wks. Eng. 108:127-128, 158. 1955.
6. Microorganisms and short filter runs. J. R. Baylis. Pure Water, Dept. of Water and Sewers, Chicago, Ill. 10:184-196. 1958.
7. The significance of microorganisms in plant design. C. J. Lauter. Proc. 11th Ann. Conf. Md.-Del. Water and Sewerage Assn., p. 67-74. 1937.
8. Treatment difficulties due to a massive crop of *Ceratium hirundinella*. K. B. Clarke. Jour. Inst. Water Eng. (Brit.) 15:233-238. 1961.
9. Microorganisms that have caused trouble in the Chicago water system. J. R. Baylis. Pure Water, Dept. of Water and Sewers, Chicago, Ill. 9:47-74. 1957.
10. Screen clogging by a rare species of algae. W. W. DeBard and J. R. Baylis. Water & Sew. Wks. 93:223-224. 1946.
11. The biological examination of water. A. T. Hobbs. Chapt. 18, p. 716-758 in Manual of British Water Supply Practice. Ed. 2. H. Heffer and Sons, Ltd., Cambridge, England. 1954.

TABLE 18. FILTER AND SCREEN CLOGGING ALGAE

Group and algae	Plate
Blue-Green Algae (Myxophyceae):	
Anabaena flow-aquae	VIII
Anacystis dimidiata (Chroococcus turgidus)	VIII
Gloeotrichia echinulata	
Oscillatoria amphibia	
Oscillatoria chalybea	VIII
Oscillatoria ornata	
Oscillatoria princeps	VIII
Oscillatoria pseudogeminata	
Oscillatoria rubescens	
Oscillatoria splendida	VIII
Phormidium	IV
Rivularia dura	VIII
Green and Yellow-Green Algae (nonmotile Chlorophyceae, etc.)	
Chlorella pyrenoidosa	VIII
Cladophora aegagropila	
Closterium moniliferum	VIII
Dichotomosiphon tuberosus	
Dictyosphaerium pulchellum	
Hydrodictyon reticulatum	VII
Mougeotia sphaerocarpa	
Palmella mucosa	VIII
Spirogyra porticalis	VIII
Tribonema bombycinum	VIII
Ulothrix variabilis	VIII
Zygnema insigne	
Diatoms (Bacillariophyceae):	
Asterionella formosa	VIII
Cyclotella meneghiniana	VIII
Cymbella ventricosa	VIII
Diatoma vulgare	VIII
Fragilaria crotonensis	VIII
Melosira granulata	VIII
Melosira varians	
Navicula graciloides	VIII
Navicula lanceolata	
Nitzschia palea	IV
Stephanodiscus binderanus	
Stephanodiscus hantzschii	I
Synedra acus	VIII
Synedra acus var. radians (S. delicatissima)	
Synedra pulchella	
Tabellaria fenestrata	VII
Tabellaria flocculosa	VIII
Pigmented Flagellates (Chrysophyceae, etc.):	
Ceratium hirundinella	VII
Dinobryon sertularia	VIII
Perindinium wisconsinense	
Trachelomonas crebea	VIII

CHAPTER XV

ADDITIONAL PROBLEMS CAUSED BY ALGAE

The widespead distribution of algae in water supplies, together with their unique combination of characteristics, allows them to exert effects in many places and in many ways. In addition to those activities discussed in the preceding chapters, the algae have been implicated in producing slime in industrial water supplies, causing coloration of water, inducing corrosion of concrete and of metals, reducing the potability of treated water by their presence in distribution systems, interfering with the chemical treatment of water, and causing illness in man and animals (1).

SLIME

Slime formation can be caused or aided by various kinds of algae, bacteria, and other organisms (2). Slime-producing algae are important in open reservoirs and in uncovered holding basins of recirculating systems. They can become a serious problem especially in the water supplies for pulp mills and food industries by causing slime spots or masses in the products. Coatings of slime may also develop on condenser tubes in industrial cooling systems and have the effect of reducing the rate of heat transfer to the water (3). Slime accumulation in the unlighted portions of distribution systems may be due to bacteria, to the tardy settling out of the coagulant, or to other agents, but not to algae.

Algal slime commonly is derived from the mucilaginous capsule or sheath which envelops the cells. The blue-green algae as a group are notorious slime producers. Their technical name, Myxophyceae, contains the prefix "myxo" which means slime or mucus. Several diatoms as well as green and red algae and a few flagellates also produce slimy sheaths or capsules. A few of the slime-forming algae are given in table 19.

COLORATION

Algal coloration of finished water is most frequent in communities that have uncovered storage reservoirs, or where the treatment of the raw water supply is not efficient in reducing the numbers of phytoplankton present. Almost any small alga capable of rapid multiplication could be involved. Complaints come from patrons when the water from the faucet is colored, or when a colored marginal ring forms at the surface of the water in the tumbler or bathtub. Colors ranging from yellow-green through green, blue-green, red, and brown to black could all be due to algae. In table 19 are listed some of the algae that have been implicated. However, colors in water may also be caused by substances other than algae.

CORROSION

Corrosion of concrete and of metals in pipes and boilers is a continual problem. Algae sometimes contribute to corrosion either directly in localized places where they may be growing or through their modification of the water by physical or chemical changes. Green and blue-green algae, along with lichens and mosses growing on the surface of submerged concrete, have caused the concrete to become pitted and friable (4).

Typical algae are unlikely to be the direct cause of corrosion of iron or steel pipes in a distribution system because most are incapable of active growth in the absence of light. However, algae have been reported to cause corrosion in metal tanks or basins open to sunlight. *Oscillatoria* growing in abundance in water in an open steel tank has caused serious pitting of the metal. The pits were bright and clean because the iron was apparently going into solution and not producing any covering compound such as an oxide or sulfide. The algal growth permitted the pitting to take place by releasing oxygen which combined with the protecting film of oxide over the steel. When the steel tank was covered to prevent entrance of light, the algae disappeared and the corrosion stopped (5).

Indirectly, algae may affect the rate of corrosion in a number of ways. Increases in organic deposits in the pipe, increases in the dissolved oxygen in the water through photosynthesis in the raw water supply, and changes in the pH, CO_2 content, and calcium carbonate content of the water can all be brought about by algae. These changes can, in turn, have a more direct relationship to corrosion and may be significant particularly on the outside surfaces of pipe buried in the ground.

ALGAE IN TREATED WATERS

The persistence of algae in the water of distribution systems tends to become more pronounced as additional surface water supplies are tapped but less evident as effective measures for reducing the plankton in the water are practiced. As most algae cannot grow and multiply without light, the only algae which would be encountered in the pipes of the distribution system would be first, those not removed in the treatment process; second, the few algae unusual in their ability to grow in the dark; and third, those that develop in an uncovered reservoir containing treated water. The algae capable of growth in the dark include some species of *Scenedesmus, Euglena, Anacystis, Coelastrum,* and *Chlorococcum.*

Since the treated water in most distribution systems has a free chlorine residual, the algae most likely to remain intact in the pipelines would be the chlorine-resistant forms. These algae might be capable of carrying into the distribution system living bacteria, presumably even pathogenic forms, which are protected from the lethal effect of the chlorine by being embedded in the gelatinous covering surrounding the algal cells (6). Algae reported to be resistant to chlorine in distribution systems include *Elakatothrix gelatinosa, Gomphosphaeria aponina, Closterium* (fig. 62), *Cosmarium*, and *Chlorella*. In one water supply receiving a normal chlorine treatment but no coagulation or filtration, counts of up to 2,200 algae/ml were recorded for the tap water. In counting, no distinction was made between living and dead organisms. Some of the most abundant genera were *Asterionella, Cyclotella, Dinobryon*, and *Synedra* (7).

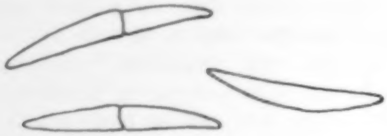


Figure 62.—*Closterium lunula*, a desmid.

Reservoirs in the distribution system can be provided with covers to keep out the sunlight and thus prevent the growth of algae. Groundwaters stored in open reservoirs are often more susceptible to prolific algal growths than are treated surface waters, possibly because their lower turbidity permits greater light penetration. The groundwaters can contain in solution a supply of nitrates, phosphates, iron, silica, and carbonic acid in quantities sufficient to support the phytoplankton and especially the diatoms. The groundwater is easily seeded with algae and other organisms which may be carried to the reservoir by the wind or on the bodies of aquatic birds. The algae can impart their characteristic odors to the stored water and these can be carried into the remainder of the distribution system (8).

Algae that persist in distribution systems can increase the organic content of the water sufficiently to deplete the residual chlorine in the water. In addition, this organic content may feed bacteria, blood worms, nematodes, copepods, freshwater sponges, bryozoa, and other undesirable organisms. Organisms that grow attached to the inner surface of the pipes are commonly known as pipe moss.

ROLE OF ALGAE IN WATER TREATMENT PROBLEMS

Interference by algae with the chemical treatment of water can be due to the changes they cause in pH, alkalinity, total hardness, and DO of the raw water, or to their increasing of the organic content carried by the water. It may be necessary, for example, to vary the dosage of chlorine in direct proportion to the quantity of algae present in order to obtain a constant amount of residual chlorine in the water.

In the clarification of water it is necessary to treat water with a coagulant aid in addition to the coagulant if the raw water has a low plankton population and low turbidity due to silt or other particles. The aid may be finely divided clay, bentonite, fuller's earth, activated carbon, or similar materials composed of finely divided insoluble particles. The addition of a small amount of the aid will furnish particles which act as centers for the formation of the floc. *Asterionella* and *Synedra* have been reported as inhibiting proper floc formation (9). While it is possible that particular kinds of algae might give more difficulty than others during coagulation and sedimentation, the total volume of all the algae is apparently more important. Sedimentation alone would permit dead algae to settle out gradually along with clay and other inorganic particles present. The living planktonic algae would tend to remain distributed throughout the water in the absence of a coagulant.

Many industrial establishments require a water with narrow ranges of variation in physical and chemical characteristics. In one Connecticut city the felting and dyeing processes were a part of the major industries, and they required a water free of color, turbidity, iron and aluminum, and with low, constant pH and hardness (10). The city water treatment plant is charged with the responsibility of supplying water satisfactory for the city's industries. The raw water supply comes from reservoirs which support populations of algae that change in concentration from day to day. As this change occurs, small daily adjustments in chemical feed, equipment, and operational methods are made in the water treatment plant in order to maintain the predetermined optimum conditions such as turbidity of not more than 2.0 at the filters, minimum filter runs of 23 hr, maximum pH of 6.7 in the treated water, minimum rates of flow of 70,000 gal/ft head loss/filter, and minimum floc size in the last flocculator of 2.0 mm.

Normally a large floc particle is obtained quickly and without agitation. Agitators are used, however, when certain free floating algae, particularly *Gomphosphaeria* and *Anabaena*, are abundant. The agitation causes smaller floc particles to be formed which in this situation gives a settled water with lower turbidity and color than would be obtained with large floc particles.

Daily blooming of algae in the reservoirs frequently induces the formation of a weak floc during coagulation in the treatment plant and allows appreciable amounts of undesired substances to remain in the water and to pass through the sand filters into the finished water. The blooming of the algae may cause the pH of the raw water to rise from 7.0 to 10.0 in a few hours. It is the high pH which causes a poor floc to be formed when alum is added. Formerly the importance of algae in causing this change was not recognized, and treatment plant operators were continually puzzled by the sudden inexplicable shift to a settled water of poor quality. During the high peak of the pH cycle the normal amount of alum which they had added to the water was insufficient to lower the pH to the point where good floc formation would occur.

In some cases, the pH of the finished water is adjusted to be within a desired range for industry by the addition of acid or alkali. The water for a certain steel mill requires approximately 800 lb of 60 percent H_2SO_4 per day to keep the pH of the water down to 8 as it is drawn from a 320-acre lake. The algae in this lake are responsible for increases in the pH of the water, and regular phytoplankton counts are made as an aid in estimating the amount of change in pH which will occur.

In another state a reservoir of 350 acres had a total hardness normally of 120 ppm. In early June of one year this suddenly dropped to 90 ppm. The DO increased from 8.3 to 13.0 ppm; the pH, from 8.6 to 8.9; the carbonate alkalinity, from 20 to 30 ppm; and the turbidity, from 9 to 18 ppm. At the same time the blue-green alga *Anabaena* which was then the dominant form increased from 750 to 4,730 areal standard units/ml. Favorable conditions were created for the precipitation of calcium carbonate and thus a softening of the water. According to the report, the many cells of *Anabaena* had utilized sufficient "half-bound" carbon dioxide in their metabolism to increase the pH, which in turn made possible the precipitation of the calcium carbonate (11). Other algae have been observed to bring about a similar change. These are listed in table 19. British experience has shown that vigorous algal growth of many kinds can reduce water hardness by as much as one-third (12).

TOXICITY OF ALGAE

Illness in man and animals has been attributed to both marine and freshwater algae. A toxic agent produced by the marine armored flagellate *Gonyaulax* (13) can cause serious illness in man following eating of clams that have fed on particular species of this genus. The poison has been described as a toxin 10 times as potent for mice as strychnine. *Gonyaulax* and *Gymnodinium* and other dinoflagellates may accumulate in very large numbers in ocean water near the shore and produce a condition known as red tide or yellow-green peril. These flagellate blooms have been reported for a number of localities throughout the world, including the coasts of California, Florida, and Texas, as well as Peru, Japan, Australia, India, Africa, and Europe. Shellfish poisoning due to *Gonyaulax* has also been reported for Quebec, Nova Scotia, New Brunswick, and Vancouver Island in Canada, and for California, Alaska, Oregon, Maine, Mexico, British Isles, Norway, France, Belgium, and New Zealand (14,15).

Many kinds of fish and other marine animals are often killed during the time of the red tide but perhaps as the result of factors other than the toxin since according to some workers the poison has little or no effect on fish. When the decaying fish are washed up on the beaches, the stench and the need for quick disposal constitute a serious problem for the communities affected. *Gymnodinium veneficum*, a species related to red tide algae, has been found to kill fish in a short time and is lethal also to shellfish, arthropods, and echinoderms (16).

Several other marine algae have been implicated as causing reef fishes to be poisonous in some areas. Large numbers of poisonous fishes are known to be herbivorous, and considerable evidence exists to indicate that these fish are poisonous as food only after they have fed on certain kinds of algae (17). In a large majority of the poisonous fishes that were examined, the blue-green alga *Lyngbya* (fig. 63) was detected in the alimentary tract. *Lyngbya majuscula* and *Lyngbya aestuarii* were the common species in the area and in the fish samples. It is interesting to find a report published in 1904 that "numbers of horses have frequently been killed by feeding on *Lyngbya majuscula* which occurs in abundance on the coral beaches in the Gulf of Manor" along the coast of India (18). Other marine algae have been found toxic to mice, but their possible toxicity to man has not been determined (19). An algal flagellate *Prymnesium parvum*, reported for Europe and common in brackish water ponds in Israel, produces an extracellular toxin which has resulted in mass mortality among fishes and in Israel is considered the most serious natural obstacle to fish breeding (20).

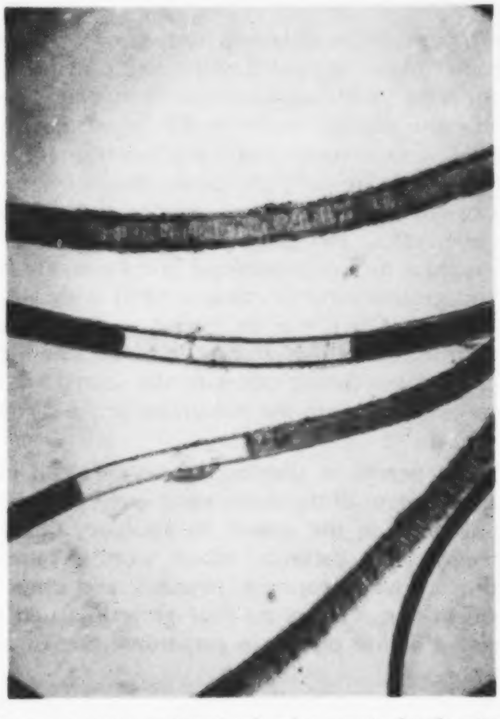


Figure 63.—*Lyngbya majuscula*, showing empty sheath extending between threads of cells.

Toxic freshwater algae affecting man have been reported in the United States and elsewhere. Contact types of dermatitis and symptoms of hay fever have been reported to be caused by blue-green algae. *Anabaena* was implicated in the former reaction (21) while *Anacystis (Microcystis)* and *Lyngbya contorta* were listed for the latter (22). In a few cases the green alga *Chlorella* has been found associated with fungi in mycotic lesions in man, but its significance has not been determined (23). Unexplained outbreaks of gastroenteritis involving thousands of people and possibly related to the water supplies have been reported in areas where extensive algal blooms were present (24). However, direct relationship between the algal blooms and the intestinal disorders in humans has not been clearly demonstrated (25). It has been suggested as a possibility that the disintegration of large amounts of blue-green algae on the sand filters of water treatment plants and the passage of toxic products into the distribution mains may be the cause of the gastro-intestinal disturbances (26).

There are many records of acute and often fatal poisoning of livestock where the animals had been drinking from ponds containing dense algal blooms (27). Animals affected have included horses, cattle, hogs, sheep, dogs, rabbits, and poultry. In all cases the algae implicated as the toxic agents are blue-greens, *Anacystis (Microcystis)* being the genus most often involved. The first alga reported as toxic was *Nodularia spumigena* (fig. 64). The several genera and species which are reported as toxic are listed in table 19. Areas which have reported poisoning of animals, presumably due to algal blooms, include Colorado, Idaho, Illinois, Iowa, Michigan, Minnesota, Montana, North Dakota, Wisconsin, and Alberta, Manitoba, Ontario, Saskatchewan, Bermuda, Argentina, Finland, U.S.S.R., Australia, New Zealand, South Africa, and Morocco (28). The outbreaks have occurred only during the summer months when algae are abundant. The symptoms associated with poisoning by the blue-green algae are generally prostration and convulsions followed by death (29).

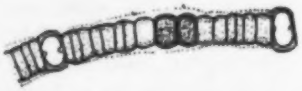


Figure 64.—*Nodularia spumigena*, the first blue-green alga reported as toxic.

In Saskatchewan particularly, there is evidence that the toxic blue-green algae can affect humans as well as animals, causing severe headache, high fever, nausea, vomiting, painful gastrointestinal upsets (including diarrhea), pains in muscles and joints of limbs, and exhaustion. Health authorities have warned persons against swimming in water containing a bloom of blue-green algae (30).

There are two reports of fresh-water dinoflagellates causing fish kills. One was in Lake Austin, Texas, and the other was in a small lake in Louisiana. In both cases the dinoflagellate *Gymnodinium* or *Glenodinum* was present in high numbers. Fish that were killed included a large number of gizzard shad which obtain food primarily by straining algae from the water. Toxicity appears to be related to the high concentration of the algal cells, a water temperature of 70° to 75°F, high pH, and length of exposure to sunlight (31,32).

Fish kills in fresh-water lakes and reservoirs have often been blamed, with considerable justification, on the algae. When there is a heavy algal growth, a reduction in the amount of sunlight due to weather conditions will reduce the photosynthetic activity of the algae. With insufficient by-product oxygen being produced the algae are forced to use in respiration the oxygen stored in the water. If this condition should exist for any length of time, the water would lose most of its oxygen, causing the algae and the fish to die of oxygen starvation.

On the other hand, normal amounts of sunshine on a very thick mat of algae can bring about a fish kill. If the mat becomes thick enough to prevent the passage of light to planktonic algae below the surface, the latter will then use up more oxygen than is produced and oxygen depletion takes place, affecting the fish.

A balance tends to exist between the amount of algae, the sunlight, and the total oxygen requirements of the fish and other aquatic organisms. A rise in water temperature might easily be the factor which stimulates an excessive growth of algae and thereby sets off the chain of events leading to oxygen starvation and a fish kill (33).

PARASITIC ALGAE

Algae are known to be living on or in the tissues of some aquatic vertebrates and in the bodies of many lower animals. They have been found in *Stentor, Paramecium, Hydra,* water sponges and mussels, snails, and turbellaria. In many cases the alga involved is *Chlorella* or *Zoochlorella*, but others found are *Carteria, Phytoconis (Protococcus), Aphrydium, Coccomyxa, Scenedesmus, Chlamydomonas,* and *Trockiscia*. The relationship between the alga and its host appears to vary from symbiosis to parasitism (34).

A few aquatic algae are known to infest the gills of fish, causing a disease which interferes with respiration and is often fatal (35). The dinoflagellate *Oodinium ocellatum* parasitizes small fresh-water fishes. Other species of this genus occur in the marine tunicates, annelid worms, and other aquatic invertebrates (36).

In connection with fish, unicellular algae are often present on the scales of mullet, and one species was improperly distinguished from another by the presence of dark spots on the scales. These dark spots were later found to be the presence of algae and the species was declared invalid. A kissing gourami at the Bronx Zoo had a greenish spot along the right dorso-lateral area, just below the dorsal fin. It was underneath the epidermis and was composed of unicellular algae. Algal growths were also found within the nasal capsule and between the eyes. Some of the algae were filamentous and identified as *Stigeoclonium*. The fish was anemic which may have been related to toxic substances from the algae (37).

In a large fish farm in Florida, swordtails and kissing gourami were found to have many algal cells in the epithelium of the skin and gills. The algae appeared to be *Mucophilus cyprini*. It is 15 to 20 microns in diameter and has 8 to 12 chloroplasts. The affected fish were emaciated and the mortality rate was high (38).

Other algae reported to be parasitic on fish in North America are *Oodinium limneticum*, a dinoflagellate, and *Cladophora*. In Japan algae have been found growing on the teeth and surrounding tissues of fish (39). In the skin of the carp, a green alga, *Chlorochytrium*, has been reported (34).

Additional algae are parasitic on higher plants. One species, *Cephaleuros virescens*, is the causal agent of red rust of tea, one of the most serious diseases for the tea-plant. It affects both leaf and stem. This same species of alga also is parasitic on coffee. *Cephaleuros* is a branching filament. Branched rhizoids extend from the filament and ramify in all directions in the host tissues. At least some of the algal cells contain chloroplasts and produce orange-to-green areas in the host (34).

Some non-filamentous colonial algae are parasitic on plants. *Chlorochytrium* which resembles *Chlorococcum* is parasitic on duck weed *(Lemna)*. It enters through a stoma or between two epidermal cells and develops as a large ellipsoidal, sometimes lobed cell between the cells of the host. This can also attack other aquatic plants such as *Elodea*, *Ceratophyllum*, and certain mosses. A red unicellular alga, *Rodochytrium* inhabits the leaves of ragweed.

A branching tubular alga, *Phyllosiphon* lives in the leaf tissues of plants of the arum family. The leaves become discolored with yellowish blotches because of orange gobules of oil that accumulate due to the irration of the parasite. The area of the leaves around the algae eventually lose their chlorophyll (40).

Some algae are parasitic on other algae. This is particularly true of certain marine red algae.

RADIOACTIVITY IN ALGAE

Algae take up and concentrate many dissolved minerals, both stable and radioactive, even from great dilutions in the water. Some bodies of water contain naturally radioactive materials, others become radioactive through contamination. The abundant alga in a naturally radioactive spring in Japan was *Calothrix parietina* (41). The spring contained 18 kinds of algae, 12 of them being diatoms.

Radioactivity may be relatively harmless to algae, but if the algae are used as food by higher organisms, then directly or indirectly the radioactive materials can be incorporated into fish. The simpler aquatic organisms may also reach crop soils through irrigation or flooding and animals may ingest the organisms when drinking from streams and ponds. From all three of these sources humans may receive the potentially harmful radioactive materials.

Experiments with *Euglena indicate* that some of the radionuclides are bound by that alga with a chemical mechanism. This bound condition enables the nuclides to pass along a food chain through *Daphnia* into bluegills. Bluegills, getting cesium from the *Euglena-Daphnia* food chain, retained about 72 percent of the element (42).

The algae may take up radioactive substances in three ways: by engulfment, by absorption through cell membranes exposed to the surrounding water, and by adsorption onto exposed surface areas. Algae do not distinguish between stable and radioactive materials. Also, because of the three methods of collecting materials they may concentrate not only materials utilized in metabolism but useless substances as well. For example, cells of *Carteria* can adsorb yttrium and can absorb strontium neither of which is used in cell activities but both of which can be radioactive (43).

The sorption of cesium-137 by algae is of particular interest because it is one of the fission products in power reactor wastes and atomic weapon fallout, and because it has an estimated half-life off 26.6 years. Table 20 shows the uptake of cesium-137 by various species of algae (44).

Algae were found to remove phosphorus from water, concentrating the tracer materials 300,000 times. Maximum accumulations of radio-phosphorus by the algae were reached in 18 days. *Spirogyra* concentrated radiophosphorus by a factor 850,000 times that of water. Algae in settling ponds concentrated the radionuclides in their structure but the release of the nuclides can be retarded in waters of low pH. This could form a zone of high activity of undesirable magnitude at the mud-water interface (45).

The concentration of radionuclides by algae can be very high, as shown in table 21. The uptake of trace elements by organisms is not a phenomenon which is peculiar to the radioactive forms of the elements. The radioisotope acts only as a tracer that demonstrates the difference between the abundance of the element in the water and in the organism. From measured amounts of radionuclides in the effluent from Hanford, Washington, reactors and in types of organisms living on the Columbia River immediately below the reactors, maximum concentration factors have been calculated for the more abundant isotopes. These are listed in table 21 (46).

The concentration factors for several isotopes are quite low in fish in comparison to those in algae and insect larvae. Thus, food chains can serve, in some cases, to reduce the concentration of radionuclides in large animals. Organisms tend to eliminate non-essential elements making a selection against such nuclides along the food chain. Also, short-lived isotopes will decay to lower levels as they pass through the chain.

Differences in the concentration factors for various isotopes among algae, insect larvae, and fish lead to different levels of radioactivity in these groups of organisms. This is indicated in table 22 (47). The short-lived isotopes con-

tribute significantly to the large quantity of radioactive materials in lower organisms, but in the fish about 95 percent of the activity originates from P^{32}.

It is obvious that radionuclides which enter fresh water streams and lakes may enter the food chain especially by means of the algae and thus appear in fish and other forms eaten by humans. The radioactive contamination levels in the organisms are affected by a number of physical, chemical, and biological factors. Fresh water communities vary so greatly from one another that monitoring of the concentrations of the radionuclides must be carried out at each locality.

REFERENCES

1. The effects of algae in water supplies. D. H. Matheson. International Water Supply Assn. General Rept. to 2d Congress. Paris, France, 82 p. 1952.
2. Microscopic organisms in water conduits. G. C. Whipple, G. M. Fair, and M. C. Whipple. Chapt. 5 in The Microscopy of Drinking Water. Ed. 4. J. Wiley and Sons, N.Y. 1948.
3. Experiences in chlorinating condenser circulating water. V. M. Frost and W. F. Rippe. Wallace and Tiernan Tech. Publ. No. 112, 32 p. 1929.
4. Biological corrosion of concrete. E. T. Oborn and E. C. Higginson. Joint Rept. Field Crops Res. Branch, Agric. Res. Service, U.S. Dept. Agric. and Bur. Reclamation, U.S. Dept. Interior, 8 p. Jan. 1954.
5. The role of algae in corrosion. H. C. Myers. Jour. Amer. Water Wks. Assn. 39:322-324. 1947.
6. Quality and quantity of plankton in the south end of Lake Michigan in 1942. J. B. Lackey. Jour. Amer. Water Wks. Assn. 36:669-674. 1944.
7. Plankton removal tests and potable water supply at Naval Station, Newfoundland. C. M. Palmer and H. H. Black. Dept. Health, Ed. and Welfare, Public Health Service, Robt. A. Taft San. Eng. Center, Cincinnati, Ohio, 60 p. (Mimeographed). Jan. 1955.
8. Covers for reservoirs for filtered waters and ground waters. Amer. Water Wks. Assn., p. 243-245 in Water Wks. Practice. Williams and Wilkins, Baltimore, Md. 1925.
9. Algae and other natural sources of tastes and odors in water supplies. G. J. Turre. Chapt. 2 in Taste and Odor Control in Water Purification. West Va. Pulp and Paper Co. N.Y. Bull. 1955.
10. Algae control at Danbury, Connecticut. E. A. Tarlton. Jour. New England Water Wks. Assn. 63:165-174. 1949.
11. Investigation of an unusual natural water softening. D. W. Graham. Jour. Amer. Water Wks. Assn. 34:589-594. 1942.
12. Freshwater biological research and water supply. W. H. Pearsall. Jour. Inst. Water Engrs. 5:482-484. 1951.
13. The Florida Gulf Coast red tide. J. B. Lackey and J. A. Hynes. Florida Eng. and Indust. Exp. Sta. Bull., Series No. 70, 23 p. Feb. 1955.
14. Mussel poisoning—a summary. H. Sommer and K. F. Meyer. In Manual for Control of Communicable Diseases in California. California State Dept. Public Health. 1948.
15. Public health significance of paralytic shellfish poison: a review of literature and unpublished research. E. F. McFarren, M. L. Schafer, J. E. Campbell, K. H. Lewis, E. T. Jensen, and E. J. Schantz. Proc. National Shellfisheries Assn. 47:114-141. 1956.
16. Two new species of *Gymnodinium* isolated from the Plymouth area. D. Ballantine. Jour. Marine Biol. Assn. United Kingdom 35:467-474. 1956.
17. Marine algae from Palmyra Island with special reference to the feeding habits and toxicity of reef fishes. E. Y. Dawson, A. A. Aleem, and B. W. Halstead. Allan Hancock Foundation Publ. Univ. Southern California. Occasional paper No. 17. 39 p. Feb. 1955.
18. Treatise on the British freshwater algae. Revised Ed. (p. 451). G. S. West and F. E. Fritsch. Cambridge Univ. Press, Cambridge, England, 534 p. 1927.
19. Observations on toxic marine algae. R. C. Habekost, I. M. Fraser, and B. W. Halstead. Jour. Washington State Acad. Sci. 45:101-103. 1955.
20. Conditions which determine the efficiency of ammonium sulfate in the control of *Prymnesium parvum* in fish breeding ponds. M. Shilo and M. Shilo. Appl. Microbiol. 1:330-333. 1953.
21. Cutaneous sensitization to blue-green algae. S. G. Cohen and C. B. Reif. Jour. Allergy 24:452-457. 1953.
22. Symptoms of hay fever caused by algae. II. Microcystis, another form of algae producing allergenic reactions. H. A. Heise. Ann. Allergy 9: 100-101. 1951.
23. The role of algae and plankton in medicine. M. Schwimmer and D. Schwimmer. Grune and Stratton, N.Y., 85 p. 1955.
24. Epidemic of intestinal disorders in Charleston, West Virginia, occurring simultaneously with unprecedented water supply conditions. E. S. Tisdale. Amer. Jour. Public Health 21:198-200. 1931.
25. Unusually mild recurring epidemic simulating food infection. R. R. Spencer. Public Health Repts. 45:2867-2877. 1930.
26. Discussion of article by W. D. Monie on algae control. T. C. Nelson. Jour. Amer. Water Wks. Assn. 33:716-720. 1941.
27. Toxic fresh-water algae. W. M. Ingram and G. W. Prescott. Amer. Midland Naturalist 52:75-87. 1954.
28. Algal poisoning in Ontario. A. G. Stewart, D. A. Barnum, and J. A. Henderson. Canadian Jour. Comparative Med. 14:197-202. 1950.
29. Toxic algae. P. R. Gorham. In Algae and Man, D. F. Jackson (ed.). Plenum Press, N.Y., p. 307-336. 1964.
30. Toxic waterbloom in Saskatchewan, 1959. H. O. Dillenbery and M. K. Dehnel. Canadian Med. Assn. Jour. 83:1151-1154. 1960.
31. Red tide of Lake Austin. K. C. Jurgens. Texas Game and Fish 11 (11): 8, 24. 1953.
32. Observation on the factors involved with fish mortality as the result of dinoflagellate bloom in a freshwater lake. R. J. Muncy. Proc. 17th Ann. Conf. Southeastern Assn. Game & Fish Comm. p. 218. 1963.
33. The algal environment in relation to fish. A. S. Kennedy. Jour. New England Water Wks. Assn. 62:196-201. 1948.
34. The structure and reproduction of the algae. F. E. Fritsch. Cambridge Univ. Press. Vol. 1: 791 p. Vol. 2: 939 p. 1935, 1945.
35. The use of copper sulfate as a cure for fish diseases caused by parasitic dinoflagellates of the genus Oodinium. R. P. Dempster. Zoologica 40:133-138. 1955.
36. How to know the Protozoa. F. L. Jahn. Wm. C. Brown Co., Dubuque, Iowa, 234 p. 1949.
37. Histozoic algal growth in fish. R. F. Nigrelli, J. J. A. McLauchlin and S. Jakowska. Copeia. No. 4:331-333. 1958.
38. Algal parasite in fish. L. Glenn, H. Bishop, and C. E. Dunbar. Prog. Fish Culturist 22:120. 1960.
39. An alga growing on the teeth and the surrounding tissues of fish. S. Isokawa. Zool. Mag. (Japan) 65:319-321. 1956.
40. The algae: a review. G. W. Prescott. Houghton Mifflin Co., 436 p. 1968.
41. The thermal algae in certain strong radioactive springs in Japan. M. Mifune, H. Hirose, and K. Tsumura. Hot Springs Science, Ansen Kagaku 10 (3): 60-64.
42. Direct and food-chain uptake of cesium-137 and strontium-85 in bluegill fingerlings. L. G. Williams and Q. Pickering. Ecology 42:205-206. 1961.
43. Uptake of cesium-137 by cells and detritus of *Euglena* and *Chlorella*. L. G. Williams. Limnol. and Oceanog. 5:301-311. 1960.
44. Concentration of cesium-137 by algae. L. G. Williams and H. D. Swanson. Science 127:187-188. 1958.
45. Radioactive wastes. Chapt. 8 in The Practice of Water Pollution Biology. K. M. MacKenthun. U.S. Dept. Interior, Fed. Water Pol. Contr. Admin., Div. of Tech. Support. U.S. Printing Office. 1969.
46. Radioactive materials in aquatic and terrestrial organisms exposed to reactor effluent water. J. J. Davis, R. W. Perkins, R. F. Palmer, W. C. Hanson, and J. F. Cline. Second Internat. Conf. on Peaceful Uses of Atomic Energy. Paper No. 393. 1958.

47. Bioaccumulation of radioisotopes through aquatic food chains. J. J. Davis and R. F. Foster. Ecology 39:530-539. 1958.

TABLE 19. ADDITIONAL PROBLEMS CAUSED BY ALGAE IN WATER SUPPLIES

Problem and algae		Algal group
Slime-producing Algae:		
Anacystis (Aphanocapsa, Gloeocapsa)		Blue-green
Batrachospermum		Red
Chaetophora		Green
Cymbella		Diatom
Euglena sanguinea var. furcata		Flagellate
Euglena velata		Flagellate
Gloeotrichia		Blue-green
Gomphonema		Diatom
Oscillatoria		Blue-green
Palmella		Green
Phormidium		Blue-green
Spirogyra		Green
Tetraspora		Green
Algae Causing Coloration of Water:	*Color of water:*	
Anacystis	Blue-green	Blue-green
Ceratium	Rusty brown	Flagellate
Chlamydomonas	Green	Flagellate
Chlorella	Green	Green
Cosmarium	Green	Green
Euglena orientalis	Red	Flagellate
Euglena rubra	Red	Flagellate
Euglena sanguinea	Red	Flagellate
Oscillatoria prolifica	Purple	Blue-green
Oscillatoria rubescens	Red	Blue-green
Algae Causing Corrosion of Concrete:		
Anacystis (Chroococcus)		Blue-green
Chaetophora		Green
Diatoma		Diatom
Euglena		Flagellate
Phormidium		Blue-green
Phytoconis (Protococcus)		Green
Algae Causing Corrosion of Steel:		
Oscillatoria		Blue-green
Algae Persistent in Distribution Systems:		
Anacystis		Blue-green
Asterionella		Diatom
Chlorella		Green
Chlorococcum		Green
Closterium		Green
Coelastrum		Green
Cosmarium		Green
Cyclotella		Diatom
Dinobryon		Flagellate
Elakatothrix gelantinosa		Green
Epithemia		Diatom
Euglena		Flagellate
Gomphosphaeria aponina		Blue-green
Scenedesmus		Green
Synedra		Diatom
Algae Interfering With Coagulation:		
Anabaena		Blue-green
Asterionella		Diatom
Euglena		Flagellate
Gomphosphaeria		Blue-green
Synedra		Diatom
Algae Causing Natural Softening of Water:		
Anabaena		Blue-green
Aphanizomenon		Blue-green
Cosmarium		Green
Scenedesmus		Green
Synedra		Diatom
Toxic Marine Algae:		
Caulerpa serrulata		Green
Cochlodinium catenatum		Dinoflagellate
Egregia laevigata		Brown
Exuviaella ballicum		Dinoflagellate
Gelidium cartilagineum var.robustum		Red
Gonyaulax catenella		Dinoflagellate
Gonyaulax polyedra		Dinoflagellate
Gonyaulax tamarensis		Dinoflagellate
Gymnodinium brevis		Dinoflagellate
Gymnodinium splendens		Dinoflagellate
Gymnodinium mitimoto		Dinoflagellate
Gymnodinium veneficum		Dinoflagellate
Hesperophycus harveyanus		Brown
Hornellia marina		Flagellate
Lyngbya aestuarii		Blue-green
Lyngbya majuscula		Blue-green
Macrocystis pyrifera		Brown
Pelvetia fastigiata		Brown
Prymnesium parvum		Flagellate
Pyrodinium phoneus		Dinoflagellate
Trichodesmium erythraeum		Blue-green
Toxic Fresh Water Algae:		
Anabaena		Blue-green
Anabaena circinalis		Blue-green
Anabaena flos-aquae		Blue-green
Anabaena lemmermanni		Blue-green
Anacystis (Microcystis)		Blue-green
Anacystis cyanea (Microcystis aeruginosa)		Blue-green
Anacystis cyanea (Microcystis flos-aquae)		Blue-green
Anacystis cyanea (Microcystis toxica)		Blue-green
Aphanizomenon flos-aquae		Blue-green
Gloeotrichia echinulata		Blue-green
Gloeotrichia pisum		Blue-green
Gomphosphaeria lacustris (Coelosphaerium kuetzingianum)		Blue-green
Lyngbya contorta		Blue-green
Nodularia spumigena		Blue-green
Rivularia fluitans		Blue-green
Parasitic Aquatic Algae:		
Oodinium limneticum		Dinoflagellate
Oodinium ocellatum		Dinoflagellate

TABLE 20. UPTAKE OF CESIUM-137 BY ALGAE

Algae	Days after dosing	Cesium-137 concentration factor
Rhizoclonium hieroglyphicum	5	1,530
Oedogonium vulgare	3	790
Euglena intermedia	14	706
Oocystis elliptica	10	670
Spirogyra ellipsospora	2	341
Spirogyra communis	5	220
Chlorella pyrenoidosa	11	154
Gonium pectorale	2	138
Chlamydonomas sp.	5	52

TABLE 21. MAXIMUM CONCENTRATION FACTORS FOR ISOTOPES IN COLUMBIA RIVER ORGANISMS

Isotope	Algae	Insect larvae	Fish
P^{32}	1,000,000	100,000	100,000
Zn^{65}	100,000	10,000	10,000
Cs^{137}	5,000	1,000	10,000
Sr^{90}	10,000	100	1,000
Na^{24}	100	100	1,000
As^{76}	10,000	1,000	100
Sc^{46}	100,000	1,000	10
Cr^{51}	1,000	1,000	10
Cu^{64}	10,000	1,000	10

TABLE 22. RELATIVE CONCENTRATION OF RADIOACTIVE MATERIALS IN VARIOUS TYPES OF ORGANISMS

Item	0 25 50 75 100
Plankton	X X X X X X X X X X X X X X X
Sessile algae	X X X X X X X X
Caddis larvae	X X X X X X X
May fly nymphs	X X X
Shiners	X X
Crayfish	X
Water	X

CHAPTER XVI

ADDITIONAL USES FOR ALGAE FOUND IN WATER SUPPLIES

Reference has already been made to the utilization of algae as indicators of domestic pollution and of natural purification in streams. They are also considered useful as indicators of the sources of a particular water supply, the pollution of groundwater supplies by surface water, the pH and temperature ranges of a stream or lake, the toxicity of industrial wastes, and the relative abundance in water of chemicals such as sodium chloride, iron, and calcium phosphate.

INDUSTRIAL USES

Algae constitute the raw material used to manufacture sodium alginate, agar, iodine, diatomaceous earth, and various food products. The food products known under various names such as amanori, kombu, kan-ten, carrageen, dulse, and limu are an important part of the diet in Hawaii, Japan, China, the Philippines, Ireland, and several other areas. These products are derived principally from marine algae and are used especially as seasonings and in soups. The alga most widely used is *Porphyra*. Most of the supply is from plants cultivated in estuaries in Japan, where the sea water is about 20 ft deep. It grows on implanted objects such as rocks or bundles of bamboo.

There are about 70 species of edible marine algae. Almost all of these are used in Hawaii while about 20 are used in Japan, 8 in the Philippines, and 5 in Canada.

Several products made from marine algae have industrial uses. *Gelidium* and related red algae are used in the production of agar, while the giant brown kelp, *Macrocystis,* is a source of the widely used alginate. The brown seaweeds, especially *Laminaria* and *Ascophyllum,* have been utilized as fertilizer and as a feed supplement for livestock in Great Britain and Ireland (1).

The utilization of fresh water algae in large amounts awaits the development of practical methods for their mass culture and harvesting (2). Their potential value as producers of concentrated protein, carbohydrates, and fat is very great, for there is no waste in the form of fibrous or woody portions that are always present in land plants. Investigations have been conducted to develop practical methods for using sewage in the production of the algae that would be suitable for animal feeds, fertilizers, and other products (3). Algae may serve in the near future as commercial sources for vitamins, hormones, and antibiotics (4). It has been estimated that about 5 million tons of algal nutrients are wasted each year in the United States alone by present methods of sewage disposal (5). If algae are grown in a closed system for treatment of sewage, there need be no waste of the nutrients (6). Many technical problems must be solved before this type of system can be widely utilized.

It is estimated that algae synthesize 90 percent of the world's organic carbon, and they are more efficient utilizers of solar energy than are higher plants. Thus it seems probable that the algae will some day be used commercially to produce a large amount of the proteins, fats, and carbohydrates required by man. Many areas of the world now have food shortages which mass culturing of fresh water algae could solve, even in dry regions, since much of the water used could be recycled. Fresh water algae are already being cultured and used in Japan. Almost all of the present production of dried *Chlorella* and related algae in Japan is sold to industries producing a fermented milk product. *Chlorella* was found to accelerate the rate of fermentation of milk.

The culture of unicellular algae is amenable to treatment as an industrial process that can operate continuously under strictly controlled conditions. *Chlorella, Scenedesmus, Ankistrodesmus,* and some other algae are easily grown in culture and can tolerate a wide range of environmental factors. Their growth is very rapid and the yield per acre per year is many times greater than for higher plants. It is estimated, for instance, that in the case of *Chlorella* 14,000 lb of protein/acre/year could be produced; the figures for grass and beans would be 600 and 370 respectively. *Chlorella* is very rich in protein as well as various vitamins and minerals. It contains all of the amino acids known to be essential for the nutrition of man and animals. Under normal conditions the organic content of *Chlorella* is approximately (by dry weight) 50 percent proteins, 20 percent carbohydrates, 20 percent lipids, and 10 percent ash. There is no waste in the form of fibers or other inedible parts, with the exception of the cellulose in the cell walls. The elements essential for human nutrition are found in algae in sufficient amounts except for calcium and sodium.

In Japan the yield of freshwater algae at the Microalgae Research Institute near Tokyo is about 13 metric tons per acre per year (dry weight). Assuming that one-half of the per capita requirements of 65 gm of protein/day was to be obtained from algae, the total area required for algae culture would be less than 1,000,000 acres to feed the present world population.

Harvesting of the algae is one of the biggest problems. Centrifugation is much in use but is presently too expensive. Enlargement of culture facilities and installing of automatic devices should reduce labor costs which at present amount to about 40 percent of the cost of production (7).

The product has an appearance, flavor, and taste similar to powdered green tea and to certain powdered seaweeds. However, the intense green of the powder gives foods a dark green to black color requiring that it be decolorized. The bleached powder is milder in odor and taste as well as in color.

ALGAE AS FOOD FOR FISH

Algae represent indirectly the primary food of the fish. The smaller algae are devoured by most of the planktonic crustaceans and by rotifers. Many very young fish feed on the zooplankton. These fish include trout, perch, and minnows. Other fish feed upon the smaller fish which fed on plankton. Algae, being the first link in the food chain, determine in a direct or indirect manner the kind and the amount of food available for fish. Recently a number of fish have been investigated which are herbivorous. Milk-fish in the brackish ponds of Thailand, Indonesia, and the Philippines feed mostly on filamentous blue-green algae and diatoms. In Australian estuaries, garfish, mullets, black bream, and cobblers frequently have very little in their guts but filamentous green algae, such as *Cladophora, Chaetomorpha,* and *Enteromorpha,* and diatoms, especially *Melosira* and *Coscinodiscus.*

A number of species of Chinese carp have been introduced into commercial pond farms in eastern Europe. There, herbivorous fish eat natural food consisting of algae or higher aquatic plants. Some prefer filamentous algae while others use microscopic planktonic algae, filtered from the water by the gill apparatus. Attempts are being made to develop an artificial pelleted food for the carp, and algae are always one of the components. In the future this kind of food will probably be the basis for food in the European carp farms.

A European teleost possesses a mouth opening with sharp edges situated on the ventral side of the head, and this makes it possible for the fish to scrape epiphytic algae from stones. Its food consists mainly of diatoms. No other European species living in cold streams matches this one as a consumer of algae.

One species of trout feeds nearly exclusively on algae by scraping them from the surface of stones on the river bottom. Other species of trout are carnivorous (8).

All of the examples given above are of fish which shorten the food chain between primary production and animal protein, between algae and fish. In many other cases algae present only the first link in the food chain that eventually reaches fish production. In each step from algae to crustacean to small fish to large fish it appears to require about 7 to 10 lb of the first step to produce 1 lb of the second. Thus at 10 lb per step, it would require 1,000 lb of algae to produce 1 lb of large fish. Fish ponds in the southern states are commonly fertilized with nutrients to stimulate higher production of algae in order to eventually produce more large fish.

ALGAE AS WATER SOURCE INDICATORS

It is often possible to identify the probable source of a sample of surface water through a determination of the number and kinds of algae and related organisms present. This is possible because the number and kinds of microorganisms which develop are related to the hydrographic features of bodies of water. The chief types of lakes, for instance, are: (a) the hard water lake with an outlet; (b) hard water landlocked lake; (c) soft water lake with an outlet; (d) soft water landlocked lake; (e) acid bog lake; and (f) alkaline bog lake.

The hard water lake with an outlet tends to have an algal flora that is predominantly the blue-green-diatom type. Typical components of a hard water landlocked lake include an equal abundance of greens and blue-greens plus some of the euglenoids and yellow-greens (Chrysophyta). In the soft water lake with an outlet, the algal flora is predominantly composed of green algae and the total number is low. The soft water landlocked lake has a scant algal flora and the filamentous forms are practically nonexistent. This type of lake may produce blooms of blue-green algae, but the number of species involved is still small. A great variety of desmids will be present in an acid bog lake, and certain species of blue-greens can be expected. Plankton forms are not abundant but filamentous ones are well developed and common. The alkaline bog lake has an algal flora which is poor both in numbers and kinds. Hard water organisms, such as *Chara, Spirogyra crassa,* and *Spirogyra decimena,* are often abundant (9). A knowledge of the typical algal floras of various lakes which represent the sources of a water supply will help, therefore, in determining the breeding grounds of the particular algae that interfere with the treatment or use of the water.

ALGAE IN WASTE TREATMENT SYSTEMS

Reference was made in chapter XII to the use of algae for production of oxygen in sewage stabilization ponds. Research carried out in California has indicated that the determination of the number and kinds of the more abundant algae in these ponds can be used as a reliable index of the progress achieved in the oxidation of the sewage (10). If the effluent contains principally *Chlorella,* the pond is assumed to be working at or over its capacity; if it contains a mixed flora, the pond can handle a heavier load. *Chlamydomonas* is one of the common forms in the mixed flora which develops when most of the organic matter is gone and mineral nutrients have been precipitated because of a high pH. *Chlamydomonas* in turn appears to excrete an organic compound which again makes the minerals available for algal growth.

Examination of the pond effluent for its algal flora may, therefore, be a useful tool for operators of sewage plants having sewage stabilization ponds. The microscopic examination would require only a few minutes, and no extensive training is required to recognize the few types of important algae. It has not yet been determined whether the procedure is applicable for use in all parts of the country.

Algae may also be put to use in the treatment of industrial wastes. By selecting and adapting particular strains of algae, yeasts, and bacteria, it may be possible to bring about, biologically, changes in industrial wastes which otherwise might be toxic or in other ways unsuitable for release into streams, lakes, or marine waters. The use of algae would be particularly advantageous when the release of oxygen into the waste is one of the required factors (6). The process has already been developed for treatment of oil wastes from refineries. The aerobic lagoon design also often includes additional features such as presedimentation, recirculation, and supplemental aeration. A few thousand stabilization ponds for treatment of industrial wastes are in use in the United States and most of them are working satisfactorily. They are being employed by the canning, chicken processing, dairy, laundry, meat packing, oil refining, pulp and paper, organic chemical, and other industries. Data are not yet available for comprehensive evaluation of loading factors and design criteria (11). Forms which are tolerant of various industrial wastes might be utilized in their treatment. These are listed in table 23. Included are *Scenedesmus bijugatus* (fig. 65) in salt brines, *Closterium acerosum* in chromium, *Chlorella variegata* in iron, *Navicula minima* in hydrogen sulfide, *Diatoma vulgare* in oil, and *Chlorogonium euchlorum* in distillery wastes.

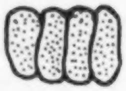


Figure 65.—*Scenedesmus bijugatus.*

ALGAE AS MARINE POLLUTION INDICATORS

Pollution of estuaries and of coastal marine waters is rapidly becoming a problem at bathing beaches and where the ocean frontage is used for residences, for industry, and for recreation. Pollution is also influencing the marine fishing and shellfish industries.

As with fresh water forms, severe pollution in salt water first tends to reduce the marine algae population to a few of the more resistant species, but the decomposition products in turn stimulate a vigorous subsequent growth of algae. In marine polluted areas in northern Europe, the sewage pollution is reported to prevent the growth of the brown rock weed, *Fucus,* while algae that are stimulated include *Blindingia minima, Enteromorpha, Ulva lactuca, Porphyra leucosticta, Erythrotrichia carnea, Acrochaetium virgatulum, Acrochaetium thuretii,* and *Calothrix confervicola*. In addition to these large seaweed algae, microscopic planktonic algae thrive in the polluted areas, causing a decrease in the transparency of the water (12). The sea lettuce, *Ulva latissima,* was stimulated to active growth by sewage in England (13). Industrial pollution in an estuary, involving principally iron sulfate, stimulated the growth of the pollution alga *Chlorella variegata* and caused the sensitive diatoms *Chaetoceros* and *Skeletonema* to settle out (14).

Marine and brackish water diatoms are being studied to determine their usefulness as indicators of pollution with either domestic sewage or industrial wastes. One apparatus for obtaining the diatoms from the water is a slide rack with floats known as a diatometer (15). Its use is being studied in both fresh and salt waters.

TEMPERATURE, pH, AND TOXICITY

Several physical characteristics of water are influenced by its utilization for industrial purposes. The largest single industrial use is cooling. In general the various classes as well as individual species of algae have minimum, optimum, and maximum temperatures for growth (16-18). The optimum temperature for diatoms is 18°-30°C, for green algae, 30°-35°C, and for blue-green algae, 35°-40°C, according to Cairns (19). He reports that the diatom *Gomphonema parvulum* grew best at 22°C, and still showed considerable growth at 34°C, while another diatom *Nitzschia linearis,* which grew best at 22°C, showed little or no growth at 30°C. Temperature changes are considered more important than any other environmental factor in influencing diatom growth (20). A few blue-green algae are capable of growth at temperatures much higher than 40°C. The optimum temperature for *Oscillatoria filiformis* is 85.2°C. Diatoms have been present in moderately hot water (40°C), but green algae are conspicuously absent in hot springs. The types of algae found in a particular stream may be a good indication of the range of temperature that the water has experienced (21-24).

Change in pH of water due to industrial wastes or to natural causes will also greatly modify the algal population. Mine wastes tend to lower the pH drastically and reduce the algal flora to a few acid-tolerant forms such as *Euglena mutabilis, Ochromonas, Chromulina ovalis, Lepocinclis ovum, Cryptomonas erosa,* and *Ulothrix zonata* (25). Additional acid-tolerant algae are included in table 23.

The majority of algae grow best in water at or near the neutral point of pH, but a considerable number, particularly among the blue-green algae, develop readily or may even grow best in water with a high pH. In cultures the optimum for *Anacystis (Microcystis)* and for *Coccochloris (Gloeothece)* has been found to be pH 10, with little or no growth below pH 8 (26).

Other physical factors such as light and turbulence also play their part in determining the particular algal flora that will develop or remain in the water. In bioassays to determine the toxicity of pollutants in water, certain kinds of fish and the crustacean *Daphnia* are being used. Algae also are being considered for the test. Some may become useful as indicators of toxicity, especially in waters where the wastes reduce the DO below that in which animals can survive. Comparatively little information is available on the tolerance limits of particular species of algae for the various toxic pollutants.

Melosira varians may be the only dominant diatom in streams polluted with oil (16). Iron, which is a pollutant from steel mills, may be toxic to most algae but the flagellates *Chromulina* and *Trachelomonas hispida* (fig. 66) may remain active. Certain diatoms are also found in iron-rich water, including many species of *Eunotia* and some large forms of *Pinnularia* (27). However, other diatoms as well as several blue-green algae and a few others appear to be tolerant to oil (28). Algae require a small amount of iron for the production of their chlorophyll and most algae grow best when the iron content of the water is between 0.2 and 2.0 mg/l. Distinct toxicity is frequently noted when it exceeds 5.0 mg (29).

Copper is well known to be toxic to many algae, but some species are reported to be resistant to limited concentrations of this metal; these include *Cymbella ventricosa*, *Calothrix braunii*, and *Scenedesmus obliquus* (fig. 67). Others are listed in tables 23 and 24.

Phenol at a concentration of 1.9 mg/l appears to have no toxic effect on diatoms (30). Chromium, bromine, and many dyes from textile operations are very toxic to algae. *Spondylomorum*, *Pediastrum* (fig. 68), and *Pandorina* are capable of developing in the presence of paper mill wastes toxic to most algae (31). Distillery wastes may limit the algae growth to a few forms such as *Chlamydobotrys*, *Chlorogonium* (fig. 69), and *Chlorobrachis* (32). Hydrogen sulfide at a concentration of 3.9 mg/l is toxic to most diatoms. Four resistant species are *Achnanthes affinis*, *Cymbella ventricosa*, *Hantzschia amphioxys*, and *Nitzschia palea* (30). Pollution of water in oil fields and in salt works with salt brine composed largely of sodium chloride may destroy most of the normal flora. Blooms of marine or estuarine forms such as the green flagellate *Dunaliella* may develop. Many diatoms and other algae are tolerant to various concentrations of salt in water. Certain species of the following algae are reported to be remarkably resistant to the presence of chromium (33): *Stigeoclonium*, *Tetraspora*, *Closterium*, *Nitzschia*, *Navicula*, and *Euglena*.

Carefully controlled bioassay experiments with known wastes and cultures of algae, followed by additional observations in polluted streams, should help in obtaining more accurate information on the toxicity to algae of some important industrial wastes.

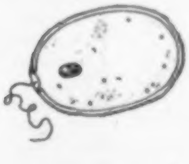


Figure 66.—*Trachelomonas hispida*.

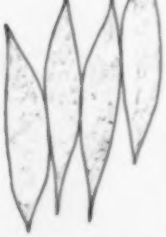


Figure 67.—*Scenedesmus obliquus*.

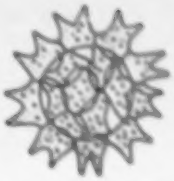


Figure 68.—*Pediastrum duplex*.

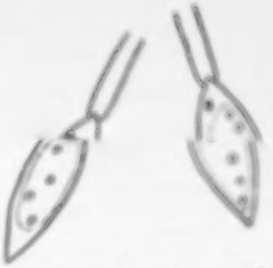


Figure 69.—*Chlorogonium euchlorum*.

REFERENCES

1. Protein quality of some freshwater algae. H. E. Schlichting, Jr. Econ. Bot. 25:317-319. 1971.
2. Some problems in large-scale culture of algae. H. W. Milner. Sci. Monthly 80:15-20. 1955.
3. Can sewage be converted into human food? L. C. Williams. Furman Univ. Faculty Stud. 2 (No. 2):16-24. 1955.
4. Algal culture from laboratory to pilot plant. J. S. Burlew. Carnegie Inst. Washington Publ. 600. 357 p. 1953.
5. Photosynthetic reclamation of organic wastes. H. B. Gotaas, W. J. Oswald, and H. F. Ludwig. Sci. Monthly 79:368-378. 1954.
6. Specialized biological treatment opens new possibilities in treatment of industrial wastes. W. B. Hart. Indust. and Eng. Chem. 48:93A-95A. Mar. 1956.
7. Mass culture of algae for food and other organic compounds. R. W. Krauss. Amer. Jour. Bot. 49:425-435. 1962.
8. Algae and fish relationships. S. Zarnecki. Chapt. 23, in Algae, Man and the Environment, D. F. Jackson (ed.). Syracuse Univ. Press. p. 459-478. 1968.
9. Lake types and algae distribution. G. W. Prescott. p. 13-22 in his Algae of the Western Great Lakes Area Exclusive of Desmids and Diatoms. Cranbrook Inst. Sci., Bloomfield Hills, Michigan, Bull. No. 31, 946 p. 1951.
10. General features of algal growth in sewage oxidation ponds. M. B. Allen. California State Water Pollution Control Board. Publ. No. 13. 1955.
11. Waste stabilization ponds, use, function, and biota. R. Porges and K. M. Mackenthun. U.S. Dept. Health, Educ., and Welfare. Taft San. Eng. Center, Cincinnati, Ohio. (Mimeographed). 40 p. 1963.
12. The algal vegetation of Oslo Fjord. O. Sundene. Skr. Norsk. Vidensk. Akad., Norway. No. 2. 244 p. 1953.
13. Treatment and disposal of industrial waste waters. B. A. Southgate. British Govt. Dept. Sci. and Indust. Res., London, England. 1948.
14. The effect of copperas pollution on plankton. C. C. Davis. No. 2 in his Studies of the Effects of Industrial Pollution in the Lower Patapsco River Area. Chesapeake Biolog. Lab. Publ. No. 72. June 1948.
15. A new method for determining the pattern of the diatom flora. Ruth Patrick, M. H. Hohn, and J. H. Wallace. Notulae Naturae, Acad. Natural Sci. Philadelphia. No. 259. 12 p. July 1954.
16. Okologische Untersuchungen uber das Phytoplankton des Klopeinersees in Karnten. C. W. Czernin-Chaudinitz. Arch. f. Hydrobiol. 51:54-97. 1955.
17. The biology of the algae. F. E. Round. Edw. Arnold, Ltd., London, Eng., 269 p. 1965.
18. Manual of phycology. G. M. Smith (ed.). Cronica Botanica Co., Mass., 375 p. 1951.
19. Effects of increased temperatures on aquatic organisms. J. Cairns, Jr. Indust. Wastes 1:150-152. 1956.
20. Factors effecting the distribution of diatoms. Ruth Patrick. Bot. Rev. 14:473-524. 1948.

21. Studies of snow algae and fungi from the Front Range of Colorado. J. R. Stein and C. C. Amundsen. Canadian Jour. Bot. 45:2033-2045. 1967.
22. Algae of some thermal and mineral waters of Colorado. M. H. Jones. Univ. Col. Stud. 24:117-119. 1937.
23. Algae from alpine areas in Rocky Mountain National Park, Colorado. L. A. Whitford and Y. C. Kim. Amer. Midl. Nat. 85:425-430. 1971.
24. The algae: a review. G. W. Prescott. Houghton Mifflin Co. 436 p. 1968.
25. Aquatic life in waters polluted by acid mine waste. J. B. Lackey. Public Health Repts. 54:740-746. 1939.
26. The mineral nutrition of *Coccochloris peniocystis*. G. C. Gerloff, G. P. Fitzgerald, and F. Skoog. Amer. Jour. Bot. 37:835-840. 1950.
27. Biological studies of polluted areas in the Genesee River system. P. W. Claassen. Part 3 in A Biological Survey of the Genesee River System. N.Y. State Dept. Conservation, Suppl. to 16th Ann. Rept. for 1926. 1927.
28. The biological effects of oil pollution in a river. R. N. McCauley. Limnol. and Oceanog. 11:475-486. 1966.
29. Limnology. Revised ed. P. S. Welch. McGraw-Hill, N.Y. 538 p. 1952.
30. Die Algenflora der Mulde. Ein Beitrag zur Biologie Saprober Flüsse. H. Schroeder. Pflanzenforschung 21:1-88. 1939.
31. The use of biological indicators in determination of stream pollution. J. B. Lackey. Univ. Michigan School Public Health. Lectures presented at Inservice Training Course in Sewage and Indust. Waste Disposal. p. 109-118. (Mimeographed.) Mar. 1948.
32. The effects of distillery wastes and waters on the microscopic flora and fauna of a small creek. J. B. Lackey. Public Health Repts. 57:253-260. 1942.
33. An ecological study of the algae of the Saline River, Michigan. J. L. Blum. Hydrobiologia 9:361-408. 1957.

TABLE 23. OTHER USES FOR ALGAE IN WATER SUPPLIES

Problem and algae	Algal group
Algae as water source indicators:	
From hard water lake with an outlet:	
Blue-green algae	Blue-green
Diatoms	Diatom
Green flagellates:	
Pandorina	Flagellate
Volvox	Flagellate
From hard water lake with no outlet:	
Green algae	Green
Blue-green algae	Blue-green
Euglenoids:	
Euglena	Flagellate
Phacus	Flagellate
Trachelomonas	Flagellate
Chrysophyta:	
Synura uvella	Flagellate
Tribonema	Yellow-green
From soft water lake with an outlet:	
Desmids	Green
Diatoms	Diatom
From soft water lake with no outlet:	
Green algae	Green
From acid bog lake:	
Desmids	Green
Anacystis thermalis f. major (Chroococcus prescottii)	Blue-green
Batrachospermum	Red
Hapalosiphon pumilus	Blue-green
Microspora	Green
Oedogonium	Green
Scytonema ocellatum	Blue-green
From alkaline bog lake:	
Chara	Green
Spirogyra crassa	Green
Spirogyra decimina	Green
Algae as indicators of temperature range of waters:	
Snow and ice algae:	
Ankistrodesmus	Green
Carteria nivale	Flagellate
Chlamydomonas nivalis	Flagellate
Chlamydomonas sanguinea	Flagellate
Chlamydomonas yellowstonensis	Flagellate
Chlorella	Green
Chodatella brevispina	Green
Chodatella granulosa	Green
Haematococcus pluvialis	Flagellate
Hormidium	Green
Koliella nivalis	Green
Raphidonema	Green
Scotiella cryptophila	Green
Scotiella nivalis	Green
Scotiella polyptera	Green
Stichococcus	Green
Tetraedron valdezi	Green
Trochiscia americana	Green
Very low temperature algae (5°-15°C):	
Achnanthes lanceolata	Diatom
Batrachospermum	Red
Chlamydomonas	Flagellate
Cosmarium pseudobroomei	Desmid
Cryptomonas erosa	Flagellate
Dactylococcopsis raphidioides	Green
Denticula tenuis	Diatom
Dinobryon cylindricum	Flagellate
Fragilaria construens	Diatom
Mallomonas alpina	Flagellate
Rhodomonas lacustris	Flagellate
Synedra acus	Diatom
Low temperature algae (15°-30°C):	
Anacystis cyanea (Microcystis aeruginosa)	Blue-green
Dactylococcopsis smithii	Green
Lyngbya limnetica	Blue-green
Microspora tumidula	Green
Nitzschia filiformis	Diatom
Nitzschia linearis	Diatom
Oedogonium tapeinosporum	Green
Spirogyra	Green
Tribonema bombycinum	Yellow-green
Hot temperature algae (40°-85°C):	
Coccochloris (Synechococcus)	Blue-green
Lyngbya contorta var. calida	Blue-green
Mastigocladus laminosus	Blue-green
Onkonema compactum	Blue-green
Onkonema thermale	Blue-green
Oscillatoria filiformis	Blue-green
Phormidium bijahensis	Blue-green
Phormidium ceylanicum f. thermale	Blue-green
Phormidium geysericola	Blue-green
Phormidium laminosum	Blue-green
Phormidium tenue	Blue-green
Phormidium treleasei	Blue-green
Plectonema notatum var. africanum	Blue-green
Pleurocapsa fluviatilis	Blue-green
Scytonema coactile var. thermale	Blue-green
Synechococcus elongatus f. thermalis	Blue-green
Synechocystis aquatilis	Blue-green
Algae as indicators of high acidity:	
Actinella	Diatom
Anomoeoneis serians	Diatom
Chlamydomonas	Flagellate
Chromulina ovalis	Flagellate
Cladophora	Green
Closteriopsis	Green
Cryptomonas erosa	Flagellate
Euastrum	Desmid
Diatoma vulgare	Diatom
Dinobryon	Flagellate
Euglena adhaerens	Flagellate

Problem and algae	Algal group
Euglena hiemalis	Flagellate
Euglena mutabilis	Flagellate
Euglena stellata	Flagellate
Euglena tatrica	Flagellate
Euglena viridis	Flagellate
Eunotia exigua	Diatom
Eunotia lunaris	Diatom
Eunotia pectinalis var. minor	Diatom
Eunotia robusta	Diatom
Eunotia tautonensis	Diatom
Eunotia tenella	Diatom
Eunotia trinacria	Diatom
Frustulia megaliesmontana	Diatom
Frustulia rhomboides var. saxonica	Diatom
Lepocinclis ovum	Flagellate
Mougeotia	Green
Navicula bryophila	Diatom
Navicula minima var. atomoides	Diatom
Navicula roteana	Diatom
Navicula subatomoides	Diatom
Navicula subtilissima	Diatom
Navicula viridis	Diatom
Ochromonas	Flagellate
Penium cucurbitinum	Desmid
Phaeothamnion	Yellow-green
Pinnularia acoricola	Diatom
Pinnularia subcapitata var. hilseana	Diatom
Pinnularia viridis var. sudetica	Diatom
Stauroneis anceps	Diatom
Tabellaria flocculosa	Diatom
Ulothrix zonata	Green
Vanheurckia rhomboides var. crassenervia	Diatom
Xanthidium antilopaeum	Desmid
Algae indicating progress of change in sewage oxidation ponds:	
Chlamydomonas	Flagellate
Chlorella	Green
Scenedesmus	Green
Algae as indicators of marine and estuarine pollution:	
Acrochaetium thuretii	Red
Acrochaetium virgatulum	Red
Actinastrum hantzschii	Diatom
Calothrix confervicola	Blue-green
Chlorella variegata	Green
Enteromorpha intestinalis	Green
Enteromorpha prolifera	Green
Erythrotrichia carnea	Red
Porphyra leucosticta	Red
Spirulina subsalsa	Blue-green
Ulva lactuca	Green
Ulva latissima	Green
Algae indicating industrial wastes:	
Distillery wastes:	
Chlamydobotrys	Flagellate
Chlorobrachis gracillima	Flagellate
Chlorogonium euchlorum	Flagellate
Oil:	
Amphora ovalis	Diatom
Ankistrodesmus	Green
Asterionella	Diatom
Chlamydomonas	Flagellate
Closterium	Desmid
Cyclotella	Diatom
Diatoma vulgare	Diatom
Euglena	Flagellate
Fragilaria	Diatom
Gomphonema herculeanum	Diatom
Gonium	Flagellate
Lyngbya	Blue-green
Melosira varians	Diatom
Meridion	Diatom
Navicula radiosa	Diatom
Oscillatoria	Blue-green
Scenedesmus	Green
Surirella molleriana	Diatom
Synedra acus	Diatom
Synedra ulna	Diatom
Tabellaria	Diatom
Trachelomonas	Flagellate
Hydrogen sulfide:	
Achnanthes affinis	Diatom
Caloneis amphisbaena	Diatom
Camphlodiscus	Diatom
Cyclotella memeghiniana	Diatom
Cymbella ventricosa	Diatom
Hantzschia amphiosys	Diatom
Navicula minima	Diatom
Neidium bisulcatum	Diatom
Nitzschia ignorata	Diatom
Nitzschia palea	Diatom
Nitzschia tryblionella var. debilis	Diatom
Surirella ovata var. salina	Diatom
Iron:	
Anomoeoneis serians var. brachysira	Diatom
Chlorella variegata	Green
Chromulina	Flagellate
Eunotia	Diatom
Gomphonema acuminatum	Diatom
Pinnularia microstauron	Diatom
Pinnularia subcapitata var. hilseana	Diatom
Stauroneis phoenicenteron	Diatom
Stenopterobia intermedia	Diatom
Surirella delicatissima	Diatom
Surirella linearis	Diatom
Trachelomonas hispida	Flagellate
Chromium:	
Closterium acerosum	Desmid
Euglena acus	Flagellate
Euglena oxyuris	Flagellate
Euglena sociabilis	Flagellate
Euglena stellata	Flagellate
Euglena viridis	Flagellate
Navicula atomus	Diatom
Navicula cuspidata	Diatom
Nitzschia linearis	Diatom
Nitzschia palea	Diatom
Stigeoclonium tenue	Green
Tetraspora	Green
Salt brine (principally NaCl):	
Achnanthidium brevipes var. intermedia	Diatom
Actinastrum hantzschii	Green
Amphiprora paludosa	Diatom
Amphora coffeiformis	Diatom
Amphora ovalis	Diatom
Anacystis	Blue-green
Calothrix	Blue-green
Chaetoceros elmorei	Diatom
Chaetomorpha	Green
Chlamydomonas ehrenbergii	Flagellate
Coccochloris elabens (Aphanothece halophytica)	Blue-green
Cyclotella meneghiniana	Diatom
Cymbella lacustris	Diatom
Cymbella ventricosa	Diatom
Diatoma elongatum	Diatom
Diploneis elliptica	Diatom
Dunaliella salina	Flagellate
Enteromorpha intestinalis	Green
Enteromorpha prolifera	Green
Entophysalis deusta (Aphanocapsa litoralis)	Flagellate
Euglena	Flagellate
Eunotia	Diatom
Frustulia rhomboides var. saxonica	Diatom
Gomphonema	Diatom
Gyrosigma attenuatum	Diatom

Problem and algae	Algal group
Hantzschia elongata	Diatom
Lyngbya aestuarii	Blue-Green
Melosira arenaria	Diatom
Meridion circulare	Diatom
Microcoleus chthonoplastes	Blue-green
Navicula anglica	Diatom
Navicula cincta var. heufleri	Diatom
Navicula cryptocephala	Diatom
Navicula gregaria	Diatom
Navicula longirostris	Diatom
Navivula minuscula	Diatom
Navicula pygmaea	Diatom
Navicula salinarum	Diatom
Navicula subtilissima	Diatom
Nitzschia apiculata	Diatom
Nitzschia epithemoides	Diatom
Nitzschia frustulum	Diatom
Nitzschia palea	Diatom
Oscillatoria	Blue-green
Pediastrum simplex	Green
Pinnularia	Diatom
Phormidium tenue	Blue-green
Scenedesmus bijugatus	Green
Scoleopleura peisonis	Diatom
Spirulina subsalsa	Blue-green
Stephanoptera gracilis	Flagellate
Synedra acus	Diatom
Synedra affinis	Diatom
Synedra pulchella	Diatom
Trachelomonas	Flagellate
Trichodesmium	Blue-green
Ulothrix	Green
Copper:	
Achnanthes affinis	Diatom
Asterionella formosa	Diatom
Calothrix braunii	Blue-green
Chlorococcum botryoides	Green
Cymbella naviculiformis	Diatom
Cymbella ventricosa	Diatom
Navicula viridula	Diatom
Neidium bisulcatum	Diatom
Nitzschia palea	Diatom
Scenedesmus obliquus	Green
Stigeoclonium tenue	Green
Symploca erecta	Blue-green
Paper mill wastes:	
Amphora ovalis	Diatom
Caloneis amphisbaena	Diatom
Cocconeis diminuta	Diatom
Cocconeis pediculus	Diatom
Cymatopleura solea	Diatom
Cymbella ventricosa	Diatom
Diatoma vulgare	Diatom
Gomphonema herculaneum	Diatom
Navicula cryptocephala	Diatom
Navicula radiosa	Diatom
Oscillatoria	Blue-green
Pandorina	Flagellate
Pediastrum	Green
Scenedesmus	Green
Spondylomorum	Flagellate
Surirella ovata	Diatom
Surirella ovata var. salina	Diatom
Synedra pulchella	Diatom
Synedra ulna	Diatom
Ulothrix	Green
Phenolic wastes:	
Achnanthes affinis	Diatom
Ceratoneis arcus	Diatom
Cocconeis placentula	Diatom
Cyclotella kützingiana	Diatom
Cymatopleura solea	Diatom
Cymbella naviculiformis	Diatom
Diatoma vulgare	Diatom
Fragilaria virescens	Diatom
Gomphonema parvulum	Diatom
Navicula cryptocephala	Diatom
Neidium bisulcatum	Diatom
Nitzschia palea	Diatom
Pinnularia borealis	Diatom
Surirella ovata	Diatom
Synedra ulna	Diatom

CHAPTER XVII

PROCEDURES FOR ENUMERATION OF ALGAE IN WATER

It is necessary to know the purpose for which any algological investigation is to be made before a particular analytic procedure is selected. In some instances there may be need to designate only certain groups or genera or species of algae. This might be the case when analyzing samples from oxidation ponds to determine the progress of sewage change or when analyzing stream samples to determine whether indicator algae or certain taste and odor producing algae are present. In other situations a knowledge of the number as well as the general groups of algae may be required. This might be needed to determine the most effective time for treating a reservoir with an algicide. The total area or volume, particularly of the diatoms, would be useful data for determining the relationship of plankton to the length of filter runs.

At many treatment plants using surface water supplies, adequate procedures include periodic inspections of the raw water supply, the treatment plant, and the distribution system for attached growths and for floating mats and blooms. This should be followed by laboratory examinations and recording of the dominant organisms present in these visible growths of algae. In addition plankton analyses of water samples from these same areas should be made at regular intervals. Information of this sort, especially when taken over a period of time and when supplemented by adequate physicochemical data, is very valuable in determining the type and application time of measures necessary for the prevention and control of problems brought about by algae.

No method has yet been widely accepted as being accurate for determining and reporting the number or volume of attached algae or of those in floating mats. Observations can be recorded as notes or indicated on an outline map to designate the location and the extent of the areas of algal growths. Changes in location and amount can then be followed by comparing the notes or map records for different dates. Identification of the algae can be accomplished with the aid of a microscope and a key such as is included in the appendix.

In the recording of plankton algae (1) the common procedure begins with the collection of a water sample from a designated location and depth. If the sample is not to be taken immediately to the laboratory for analysis, it is preserved by the addition of formaldehyde. Refrigeration is often satisfactory for one- or two-day preservation. The plankton in the sample are then concentrated by means of a centrifuge or a Sedgwick-Rafter sand filter. The writer has found a simple procedure to be the addition of a polyacrylamide gel to a small portion of the sample to absorb some of the water and leave the algae concentrated in the remainder of the sample. Using the concentrate, 1 ml is placed in a Sedgwick-Rafter counting cell and enumeration of the organisms is made with the aid of a compound microscope fitted with a Whipple ocular micrometer. The magnification commonly used is 100X, which is obtained by means of a 10X ocular and a 10X objective. With microscopes suitable for this type of analysis, the field of view, as delimited by the ocular micrometer, can be adjusted to cover 0.001 ml of the concentrate. The plankton organisms appearing in 10 fields are counted and, from their total, the number of organisms per milliliter, liter, or gallon of the unconcentrated water sample can be calculated (2). Instead of separate fields, one or more strips may be counted crosswise or lengthwise of the plankton cell, the total area determined, and the numbers per mm extrapolated from this.

Quantitative records for each genus or species may be reported separately as well as the totals for the major groups of algae. The enumeration may be in number of cells, number of clumps (isolated cells plus colonies), areal standard units, or cubic standard units. Several variations of the clump count method are in use. No single method of enumeration has been selected as a standard procedure to be followed by water treatment laboratories. However, the clump count procedure is probably the simplest method and also the basic one, since the others are often derived from it by extrapolation.

The low magnification of 100X commonly used in counting plankton, together with the loss of significant numbers of algae during preservation and concentration of the samples, results in plankton values lower than those actually present. It has been estimated that many waters contain a larger volume of minute nannoplankton than of the larger forms readily visible under low magnification. In one experiment the use of a nannoplankton counting slide (fig. 70) gave an average clump count of 3,055 algae/ml, while the count with the Sedgwick-Rafter slide was only 1,165 (3). When samples from four different water sources were used, the count obtained using the nannoplankton slide was significantly higher in each case than that derived by the Sedgwick-Rafter slide because the latter's lower magnification missed many small algae.

A number of pigmented flagellates and diatoms are so small that the very high magnification of an oil immersion objective lens is required for their identification and enumeration. Even the nannoplankton slide cannot be used with the oil immersion lens because of its very short focal length. However, if a drop of known volume of the concentrate is placed on a standard microscope slide and covered with a No. 1 cover glass so that the drop spreads out to occupy the area beneath it, the organisms can be counted for a known portion of this area using the oil immersion lens, and an extrapolation may then be made to indicate the number per milliliter (4).

Special care may have to be taken to obtain accurate records of some of the algal flagellates that are taste and odor producers or that may be indicators of clean water. When preserved in formalin, they may be changed to such an extent that they are difficult to identify (4). They become distorted in form or altered in color, and the flagella are lost. This is true particularly of *Cryptomonas, Chroomonas, Rhodomonas, Chromulina, Synura, Uroglenopsis, Eudorina, Mallomonas,* and *Merotrichia.* Even *Euglena* may be so distorted as to prevent its identification as to species. Unpreserved samples may be required, therefore, when accurate records of these sensitive algae are needed.

If there is special reason for enumerating all kinds and sizes of plankton in a water supply, the usual procedures may have to be modified. For the larger forms (mesoplankton), a 100-1 water sample is passed through a silk bolting cloth net, size 25, which has 200 meshes to the linear inch and apertures 30-40 microns wide. The organisms caught by the net are then washed into 5 percent formalin with a final volume of 100 ml. This would give a concentration of 1,000 to 1, which might be too high and need dilution for easier counting. Enumeration may be accomplished using a 1-ml sample in a Sedgwick-Rafter slide having a magnification of 25X. The count should be limited to organisms 30 microns or more in width or diameter, principally the ciliates, crustacea, and other animal forms rather than algae. Extrapolation depends on the actual sample concentration used.

The smaller forms of plankton can be obtained in numbers sufficient for counting by using the Foerst centrifuge for concentrating the sample. At a speed in excess of 15,000 rpm, the 500 ml are centrifuged at a flow that permits completion in 3 minutes. The concentrate can then be washed into a bottle and the volume brought up to 20 ml. This gives a concentration of 25-1, which may have to be reduced if the algae are found to be too numerous per field under the microscope.

Enumeration of the organisms in the concentrate is first made using the common procedure, employing a Sedgwick-Rafter slide under a magnification of 100X. A concentration providing from 10 to 100 organisms per microscopic field tends to reduce the counting error, providing the range in width or diameter of the organisms is 5 to 30 microns (microplankton). The forms that are 1 to 5 microns in width or diameter (nannoplankton) can be enumerated with much greater precision by using a counting slide which permits a magnification of 430X. Some specialized work may require a magnification of approximately 1,000X.

The combined results of the three procedures are then summarized as follows: net (meso-) plankton, no. per 100 ml; microplankton, no. per ml; and nannoplankton, no. per ml. A typical form for use in recording the results of the analysis for plankton algae is shown in figure 71.

The interpretation of plankton records has seldom been based on a predetermined set of criteria, but there are a number of aids which at least have a limited or localized use. For example, a water source for which the environmental factors are not too variable from year to year

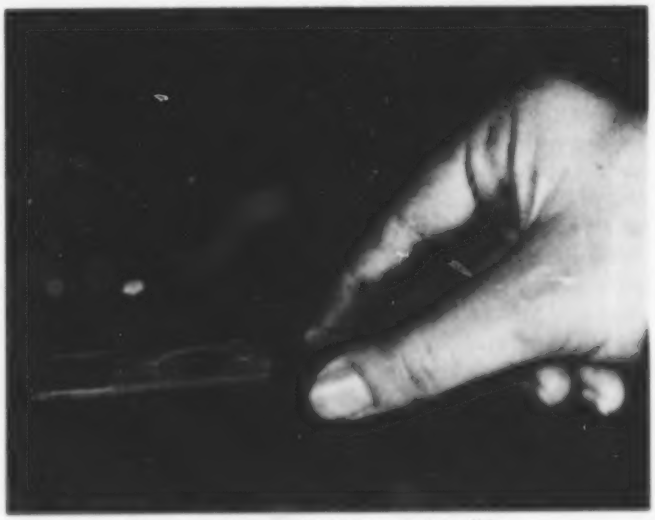


Figure 70.—Nannoplankton counting slide.

ALGAL PLANKTON RECORD

Locality............ Station No.... Collected...... 19.. Hr..

Type of analysis (Meso-, Micro-, Nanno-)

Organisms	Number per field										Total	No. per ......
(Diatoms)												
(Greens)												
(Blue-Greens)												
(Pigmented flagellates)												
Total algae												
Unpigmented forms												
Total organisms												
Pseudoplankton												
Grand total												

Information by Collector:

1. Collected by............
2. Depth............
3. Volume of sample............
4. Preservative (kind and amt.)............
5. Weather............
6. Visible algal growths............
7. Water temp............ pH............
8. Turbidity............
9. Raw water odor............
10. Threshold No. Raw............
    Finished............
11. Length of filter run............
12. Other data............

Information by Examiner:

1. Analyzed by............
2. Date............
3. Method of concentration............
4. Amt. of water concentrated............
5. Amt. of concentrate............
6. Concentration............
7. Type of counting cell............
8. Magnification used............
9. Area of microscopic field............
10. Factor for No. per ml............
11. Interpretation of results............
12. Treatment recommended............

Figure 71.—Typical form of algal plankton record.

would tend to produce similar amounts of algal growth each year. Experience indicates that this constitutes a useful working basis. Pearsall et al. (5) make the following statement: "We should expect, on this basis, that each year we might get algal growth that would tend to consist of a similar number of cell divisions in succession, to show a similar rate of growth and to yield a similar maximum number. It is clear that the possibility of forecasting depends largely upon this being approximately correct, as it appears to be." Thus, the plankton records of the previous years may give good clues as to particular times during each season when large numbers or particular types of interference organisms are likely to appear.

Pearsall et al. emphasize in addition that the form and structure of particular plankton are indicative of whether their numbers will increase or decrease. They state that "populations of algae that are not growing or that are approaching their numerical maximum tend to show certain changes in appearance. When these changes can easily be recognized, they afford useful indications of the end of a period of algal growth. This is often extremely useful when the question arises of whether or not to apply treatment."

In some areas the plankton count of the raw water has been correlated with the threshold odor test, and in one state the plankton count of the raw water has been suggested as a means of predicting the probable plankton count of the finished water following coagulation and rapid sand filtration (6).

The number of organisms and the number of areal standard units of organisms have been used to determine the amount of trouble to be expected and the time when treatment should begin. Thus, Whipple (7) stated that "when organisms were less than 500 per cc they would cause no trouble; between 500 to 1,000 per cc little trouble; between 1,000 and 2,000 noticeable trouble; between 2,000 and 3,000 decided trouble; and above 3,000 trouble would be serious."

At one treatment plant where lake water was being used, the length of the filter run was found to be reduced rapidly when areal standard units of algae increased from 50 to about 300. When the areal standard units of algae totaled 50 the probable run was 70 hr; with 100 areal units, the filter run dropped to 35 hr; with 200 units, 18 hr; with 400 units, 13 hr; and with 1,000 units, 6 hr.

A diatometer has been described for sampling the diatom population of streams (8). By enumerating and identifying up to 8,000 or more diatom specimens obtained from the diatometer, it is possible through statistical analysis to determine the frequency distribution and to construct a truncated normal curve for the sample. The height and position of the mode, shape of the curve, number of frequency intervals, number of observed species, number of species in the theoretical universe, and number of specimens required for construction of the curve are reported to be important in evaluating the data for indications of water pollution. Thus, when the water is relatively free of pollution, the number of species in the mode is high (generally between 20 and 28), the mode is located between the second and fourth intervals, the curve covers only 10 or 11 intervals, the number of observed species is generally between 120 and 180, the theoretical universe contains from 150 to 210 species, and the number of specimens required for the count is low (approximately 8,000).

In stream segments affected by pollution the number of species in the mode, the number of observed species, and the number in the theoretical universe will all be reduced in varying amounts corresponding to the degree of pollution.

In stream segments slightly enriched by nontoxic organic materials, the height of the mode remains about the same as that for the clean water station but the curve extends to the right as a "tail." If pollution increases or toxic materials are also present, the height of the mode will decrease, the tail will usually extend still farther, the curve may cover as many as 14 to 16 intervals, and up to 40,000 specimens must be counted before the mode is evident. Because diatoms can be obtained in large numbers in surface waters, this type of statistical analysis can be made. This and other procedures for detection of pollution are described in the chapter on Algae as Indicators of Water Quality.

In summary, it is evident that of the many procedures that can be used for listing and counting algae, it is necessary to select those that will produce the amount and kind of information needed for satisfactory treatment and use of each particular water supply. In addition to Standard Methods (1), other major references are Biological Field and Laboratory Methods (9) and Handbook of Phycological Methods (10).

REFERENCES

1. Biological examination of water. Part 1000 in Standard Methods for the Examination of Water and Wastewater. Ed. 14. Amer. Public Health Assn., Washington, D.C. 1975.
2. Simplified procedures for collecting, examining and recording plankton in water. W. M. Ingram and C. M. Palmer. Jour. Amer. Water Wks. Assn. 44:617-624. 1952.
3. A new counting slide for nannoplankton. C. M. Palmer and T. E. Maloney. Amer. Soc. Limnol. and Oceanog., Special Publ. No. 21, 6 p. 1954.
4. The manipulation and counting of river plankton and changes in some organisms due to formalin preservation. J. B. Lackey. Public Health Repts. 53:2080-2093. 1938.
5. Freshwater biology and water supply in Britain. W. H. Pearsall, A. C. Gardiner, and F. Greenshields. Freshwater Biolog. Assn. of the British Empire, Sci. Publ. No. 11, 90 p. 1946.
6. Numerical rating of water supplies. Section 14, Table 1416, in Manual of Water Supply Sanitation. Minnesota Dept. Health, Minneapolis, Minn. 1961.
7. Records of examination. G. C. Whipple, G. M. Fair, and M. C. Whipple. Chapt. 6 in The Microscopy of Drinking Water. Ed. 4. J. Wiley and Sons, N.Y. 1948.
8. A new method for determining the pattern of the diatom flora. Ruth Patrick, M. H. Hohn, and J. H. Wallace. Notulae Naturae, Acad. Natural Sci. Philadelphia. No. 259. 12 p. July 1954.
9. Biological field and laboratory methods for measuring the quality of surface waters and effluents. C. I. Weber. U.S. Environmental Protection Agency, Cincinnati, Ohio. EPA Report No. 670/4-73-001. 187 p. 1973.
10. Handbook of phycological methods. J. R. Stein. Cambridge Univ. Press. 448 p. 1973.

CHAPTER XVIII

CONTROL OF ALGAE

It is better to anticipate and prevent problems caused by algae than to delay until they become serious. Effective control of algal growth requires adequate records as to the numbers, kinds, and locations of algae in the water supply.

Control of algae applies to the raw water supply, to the treatment plant, and to the distribution system. The use of algicides will be considered in more detail under raw water applications, although similar procedures may sometimes be applied in the other two control areas.

CONTROL IN RAW WATER SUPPLIES

The application of an algicide is frequently carried out to prevent or destroy the excessive growths of algae which occur as blooms, mats, or as marginal growths representing high concentrations of plankton. However, the algicide may sometimes be applied to control relatively low concentrations of certain algae such as *Synura* and *Uroglenopsis*, which may cause trouble even in small numbers.

Copper sulfate is the only algicide in common use on water supplies at present, although chlorine may serve as an algicide as well as a bactericide or an oxidizing agent. The blue stone or copper sulfate, toxic to many algae at comparatively low concentrations, is ordinarily non-lethal to fish at the strengths recommended and is relatively inexpensive. However, in alkaline water it precipitates quickly as copper carbonate and more slowly as copper hydrate, and in such instances it is considered to be effective as an algicide for only a short time following its application. Bartsch (1) emphasizes that the dosage should be dependent upon the alkalinity of the water and states that the following rule has been used successfully in various midwestern lakes: If the methyl orange alkalinity is less than 50 ppm the rate should be 5.4 lb/acre. In the waters with a high alkalinity the dosage is not dependent upon depth since precipitation would make it ineffective below the surface.

The various genera and species of algae are not all alike in their reaction to copper sulfate, and this factor has frequently been neglected in determining the concentration of the algicide to be applied. A number of the very minute planktonic green algae are very resistant to the toxic effects of blue stone. The stoneworts, *Chara* and *Nitella*, are also considered to be resistant as are a few of the green flagellates and some of the filamentous blue-green algae. The diatoms as a group are relatively susceptible, but they have often developed in large numbers following the destruction of other algae through treatment with copper sulfate.

Fortunately a considerable number of the taste and odor and filter clogging algae are very susceptible to low concentrations of this algicide. All of the following interference algae are normally considered to be very susceptible to copper sulfate: *Asterionella, Fragilaria, Spirogyra, Dinobryon, Synura, Anabaena*, and *Anacystis (Microcystis)*. A more complete list of the genera of algae grouped according to their reported susceptibility to the toxic effect of copper sulfate is given in table 24.

The lowest concentration of copper sulfate which is toxic for a particular alga also varies according to the abundance of the alga, the temperature of the water, the alkalinity of the water, the amount of organic material in the water, and other factors. Thus, the listing of a specific concentration of an algicide as the minimum effective dosage is not reliable unless these other factors have first been taken into consideration. In table 24, therefore, the grouping of the algae is by very general ranges in the dosage required for treatment. The information used in preparing table 24 was obtained from several sources, including Hale (2), Cox (3), Prescott (4), Maloney and Palmer (5), Pearsall et al. (6), Matheson (7), Taft (8), Smith (9), Snow (10), Huff and House (11), and Moore and Kellerman (12).

A number of chemical compounds are algicidal. The most promising of these include the inorganic salts (copper sulfate, potassium permanganate), chlorine and its compounds, and organic compounds such as rosin amines, antibiotics, quinones, substituted hydrocarbons, quaternary ammonium compounds, amide derivatives, and phenols (13). The chemicals, to be selected as satisfactory for use in domestic water supplies, will have to be not only economically feasible but also nontoxic to animal life and to plants other than algae. Algicides should be used only where careful plankton records are kept, which would permit early localized treatment to prevent undesirable species of algae from increasing in number. Algicides which are selectively toxic to the algae which produce tastes and odors, mats or blankets, bloom, slimes, and other undesirable conditions, and clog filters would be particularly valuable (figs. 72a and 72b).

A pretreatment basin may simplify the control of algae and algal odors when the raw water has a high algal productivity. The algicide is released continuously into the water as it enters the basin. Cement baffles installed in the basin and arranged alternately from the two sides force the water to flow zig-zag through the basin before reaching the outlets. For one supply in Wisconsin where

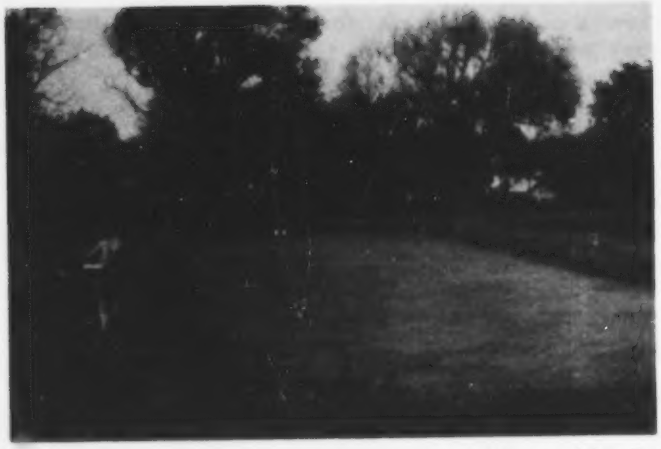


Figure 72a.—Experimental testing of a potential algicide: Applying the algicide to a blanket of algae.

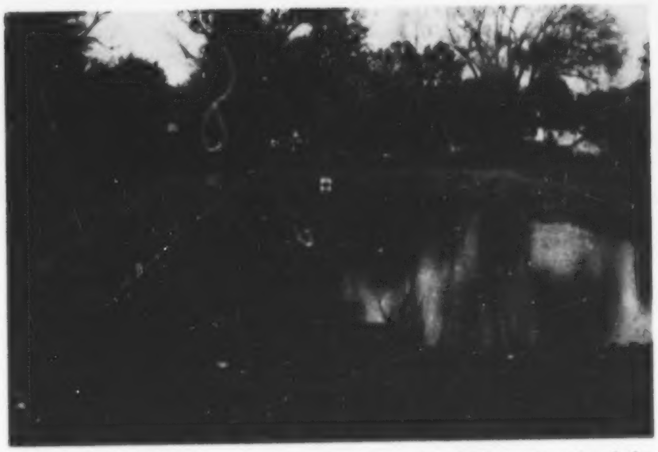


Figure 72b.—Experimental testing of a potential algicide: Result of the test: Blanket of algae has disappeared.

this procedure has been in use, the algal population is consistently and radically reduced. The threshold odor number has also been reduced an average of 67 percent (14).

Continuous treatment with copper sulfate of Croton Lake Reservoir in New York was established in 1925. The copper sulfate dosage over a period of almost 20 years averaged 0.18 mg/l and the overall reduction of plankton for this period was 65 percent (15).

A number of methods other than algicidal are in use for the control of algae in raw water supplies. An increase in turbidity due to silt will tend to reduce the phytoplankton population by limiting the penetration of light that is essential for the growth of algae. Thus, in shallow reservoirs fish which stir up the bottom mud and make the water turbid will aid in controlling plankton populations. A turbidity of 100 ppm in rivers may be sufficient to cause plankton algae to disappear but they quickly reappear as the turbidity decreases (16).

Attached algae and water weeds can become a problem in the shallow margins of lakes and reservoirs. When sodium arsenite cannot be employed, these forms are often difficult to control (17). The common procedure is to cut them or pull them out. One Connecticut utility riprapped the shore of the reservoir in an attempt to eliminate their growth.

Mechanical removal of algae may be the simplest way to dispose of massive growths which become detached and washed ashore or collect in localized areas of the reservoir. This is of particular importance when the reservoir or lake is used for recreational purposes as well as for domestic water supply. Reduction in the amount of plankton algae in a lake has been attempted by passage of the water through a rapid sand filter, the filtered water being returned to the lake (18). The backwash containing the algae collected by the filter can be used as a land fertilizer or disposed of in a lagoon.

For new reservoirs, clearing the site of vegetation and organic debris before filling will reduce the nutrients that otherwise would be present to stimulate algal growths. For all water supply reservoirs, provisions should be put into effect as early as possible for keeping the inflow of nutrients to a minimum. These would include measures for reducing the runoff from agricultural land and the selection of a supply as free as possible of upstream sewage effluents and other organic wastes.

When a reservoir receives its water from a stream there is a period of time after which the stream plankton dies out in the reservoir and before the reservoir plankton has had time to develop. The ideal period of storage, as far as water with a low plankton count is concerned, may therefore be between 10 and 14 days rather than the longer period of 28 to 30 days often recommended in the past. It is not usually possible, of course, for the capacity of the reservoir to be governed by this consideration (19).

The particular position and depth of the raw water supply intake in a reservoir or lake often predetermines the quality of the water which will enter the treatment plant. In order to ascertain the optimum position and depth for the intake, a knowledge of the biological as well as the chemical and physical characteristics of the water at various locations is required. For one water supply in Europe, 3 years of investigating plankton and water temperature indicated that a depth of 60 m was to be recommended for the intake. This depth was below the area of greatest density of plankton and below the autumn thermocline and the strata of greatest decomposition and mineralization of organic matter. No important improvement in quality of water would have been obtained by placing the intake at a greater depth (20).

RECREATIONAL WATERS AND FISH PONDS

Control of algae in recreational waters and fish ponds depends upon the types and location of the algae. Planktonic forms can be treated as in reservoirs with copper sulfate or other algicides. Attached algae, especially filamentous forms, are often hard to control. *Pithophora* is a common and abundant branching filamentous form in the warm waters of farm fish ponds in southern states. The algicide rosin amine D acetate (RADA) has been found effective in controlling *Pithophora* (21) and the attached filamentous alga *Ulothrix* present in cooler waters in the northern states (22). *Cladophora*, especially in the Great Lakes, can be difficult or impossible to control. In areas of limited water supply temporary control has been effected by the use of chlorophenyl dimethyl urea (23). In irrigation waters many algicides cannot be used since they are also toxic to crop plants. *Cladophora* is one of the most abundant of the attached algae in the irrigation canals. A mechanical method of dragging a chain through the canal has frequently been used to dislodge filamentous algae and other water weeds (24).

CONTROL IN TREATMENT PLANTS

Control of algae in the water treatment plant involves primarily the processes of coagulation, sedimentation, and filtration. Well regulated coagulation with sedimentation will often remove up to 90 percent of the algae, and in some cases 95-96 percent removal has been reported. A similar percentage of removal may occur in a rapid sand filter that is run efficiently. Assuming 90 percent removal by each of the two processes, 1,000 algae/ml in raw water would be reduced to 100 by coagulation and to 10 by filtration. However, if the removal was only 70 percent in each case, the treated water would still contain 90 algae/ml. The percentage removal by coagulation tends to be low when the number of algae in the raw water is low, but the efficiency of the process can be improved through the use of a coagulant aid such as activated silica.

Treatment with chlorine is often carried out in the plant primarily to destroy pathogenic organisms, but the dosages commonly used are sufficiently high to be toxic also to many algae. However, dead as well as living organisms can cause tastes and odors and clog filters. Coagulation of motile algae such as *Euglena* may be improved by prechlorination. When plain sedimentation is used, prechlorination will kill many of the algae and facilitate their settling out, since their motility is stopped and their buoyancy due to oxygen production in photosynthesis is reduced.

A process known as micro-straining is being used in some treatment plants, particularly in England. This involves the passing of the water through a finely woven fabric of stainless steel. The size of the openings of the mesh determines the size of the plankton organisms removed from the water. The micro-strainer is usually in the form of a partially submerged drum. While it revolves, that portion exposed to air is backwashed with jets of water (25).

The use of absorbents such as activated charcoal may be required to remove tastes and odors or other algal products from water in the treatment plant as was described in chapter XIII.

Growths sometimes develop to such an extent that the treatment basin has to be emptied of water and the walls then scraped free of algae. This may also be done for swimming pools when the walls and steps would be cleared of algae using a wire brush. Removing the slippery surface growth makes the pool safer and improves its appearance.

CONTROL IN DISTRIBUTION SYSTEMS

Control of algae in the distribution system is generally limited to the use of algicides in open reservoirs containing treated water. A permanent control would involve covering the reservoir to exclude light in order to prevent the algae from developing. Where covering is considered too costly, chlorine or copper sulfate is required at least during the warmer months. When the former is used certain chlorine-resistant algae sometimes tend to become predominant. One of these is a minute desmid belonging to the genus *Cosmarium*. Most of the algae in the distribution system either develop in the exposed reservoirs or are transient organisms remaining in the water after its passage through the treatment plant. The majority of the organisms capable of multiplying in the pipes of the distribution system are not algae but are heterotrophic forms represented by various bacteria, fungi, protozoa, worms, copepods, and other small aquatic animals.

SUMMARY OF CONTROL METHODS

Control of algae in water supplies may thus involve the use of algicides; the mechanical cleaning of settling basins, filters, intake channels, and reservoir margins; the modification of coagulation, filtration, chemical treatment, or location of the raw water intake; and, finally, the modification of the reservoir to reduce the opportunities for massive growths. Control of tastes, odors, and other algal products involves additional procedures such as the use of absorbents and the removal of organic deposits from settling basins and distribution lines. Effective control of algae is dependent upon adequate procedures for detecting their presence and interpreting the significance of any change in their numbers and kinds.

REFERENCES

1. Practical methods for control of algae and water weeds. A. F. Bartsch. Public Health Repts. 69:749-757. 1954.
2. The use of copper sulphate in control of microscopic organisms. F. E. Hale. Phelps Dodge Refining Corp., N.Y. 1950.
3. Water supply control. C. R. Cox. N.Y. State Dept. Health, Bur. Environmental San., Bull. 22. 279 p. 1952.
4. Objectionable algae and their control in lakes and reservoirs. G. W. Prescott. Louisiana Municipal Rev. 1, Nos. 2 and 3. 1938.
5. Toxicity of six chemical compounds to thirty cultures of algae. T. E. Maloney and C. M. Palmer. Water and Sewage Wks. 103:509-513. 1956.
6. Freshwater biology and water supply in Britain. W. H. Pearsall, A. C. Gardiner, and F. Greenshields. Freshwater Biolog. Assn. of the British Empire, Sci. Publ. No. 11. 90 p. 1946.
7. The effects of algae in water supplies. D. H. Matheson. International Water Supply Assn., General Rept. to 2d Congress, Paris, France. 82 p. 1952.
8. Water and algae—world problems. C. E. Taft. Educational Publishers, Inc., Chicago, Ill. 236 p. 1965.
9. Ecology of the plankton algae in the Palisades Interstate Park, including the relation of control methods to fish culture. G. M. Smith. Roosevelt Wildlife Bull. 2(2):95-195. 1924.
10. The most troublesome algae in New England waters. E. A. Snow, Jr. Jour. New England Water Wks. Assn. 72:[illegible]. 1958.
11. Copper sulfate treatment of St. Paul, Minnesota water supply. N. L. Huff and G. O. House. Jour. Amer. Water Wks. Assn. 3:[illegible]. 1916.

12. A method of destroying or preventing the growth of algae and certain pathogenic bacteria in water supplies. G. T. Moore and K. F. Kellerman. U.S. Dept. Agr., Bur. Plant Indus. Bull. No. 64. 44 p. 1904.
13. Evaluation of new algicides for water supply purposes. C. M. Palmer. Jour. Amer. Water Wks. Assn. 48:1133-1137. 1956.
14. Pre-treatment basin for algae removal. A. J. Marx. Taste and Odor Control Jour. 17 (No. 6):1-8. 1951.
15. Methods of controlling aquatic growths in reservoirs. B. C. Nesin and R. L. Derby. Jour. Amer. Water Wks. Assn. 46:1141-1158. 1954.
16. Plankton ecology of the Licking River, Ky. J. B. Lackey. U.S. Public Health Service, San. Eng. Div., Water and Sanitation Investig., Cincinnati, Ohio. 14 p. (Mimeographed.) 1942.
17. A study in the chemical control of aquatic vegetation. M. M. Boschetti. Sanitalk 5 (No. 2):21-25. 1957.
18. Control of algae, a means of prolonging the life of lakes. H. C. Leibee and R. L. Smith. Wastes Eng. 24:620-621. 1953.
19. The reservoirs of the Metropolitan Water Board and their influence upon the character of the stored water. E. W. Taylor. Proc. International Assn. Theoretical and Appl. Limnol. 12:48-65. 1955.
20. The limnological conditions for a large water-supply intake on the Uberlinger Lake (Lake Constance). R. Muckle. Gas-u Wasserfach 97:213-222. 1956.
21. Control of a branched alga, *Pithophora*, in farm fish ponds. J. M. Lawrence. Prog. Fish Culturists. 16(2):83-87. 1954.
22. Control of *Ulothrix zonata* in circular ponds. L. D. Johnson. Prog. Fish Culturist 17 (3):126-128. 1955.
23. Control of algae with chlorophenyl dimethyl urea. T. E. Maloney. Jour. Amer. Water Wks. Assn. 50:417-422. 1958.
24. A study of the algae of irrigation waters. J. D. Wien. Second Ann. Progress Rept. 26 p. 1959. Arizona State Univ., Tempe, Ariz.
25. Micro-straining. P. L. Boucher. Jour. Institution Water Engrs. 9:561-595. 1955.

TABLE 24. RELATIVE TOXICITY OF COPPER SULFATE TO ALGAE

Group	Very susceptible	Susceptible	Resistant	Very resistant
Blue-green	Anabaena, Anacystis, Aphanizomenon, Gomphosphaeria, Rivularia	Cylindrospermum, Oscillatoria, Plectonema	Lyngbya, Nostoc, Phormidium	Calothrix, Symploca
Green	Hydrodictyon, Oedogonium, Rhizoclonium, Spirogyra, Ulothrix	Botryococcus, Cladophora, Oscillatoria Enteromorpha, Gloeocystis, Microspora, Phytoconis, Tribonema, Zygnema	Characium, Clorella, Chlorococcum, Coccomysa, Crucigenia, Desmidium, Draparnaldia, Golenkinia, Mesotaenium, Oocystis, Palmella, Pediastrum, Staurastrum, Stigeoclonium, Tetraedron	Ankistrodesmus, Chara, Coelastrum, Dictyosphaerium, Elakatothrix, Kirchneriella, Nitella, Pithophora, Scenedesmus, Tetrastrum
Diatoms	Asterionella, Cyclotella, Fragilaria, Melosira	Gomphonema, Navicula, Nitzschia, Stephanodiscus, Synedra, Tabellaria	Achnanthes, Cymbella, Neidium	
Flagellates	Dinobryon, Synura, Uroglenopsis, Volvox	Ceratium, Cryptomonas, Euglena, Glenodinium, Mallomonas	Chlamydomonas, Peridinium, Haematococcus	Eudorina, Pandorina

PLANKTON ALGAE IN LAKES AND RESERVOIRS

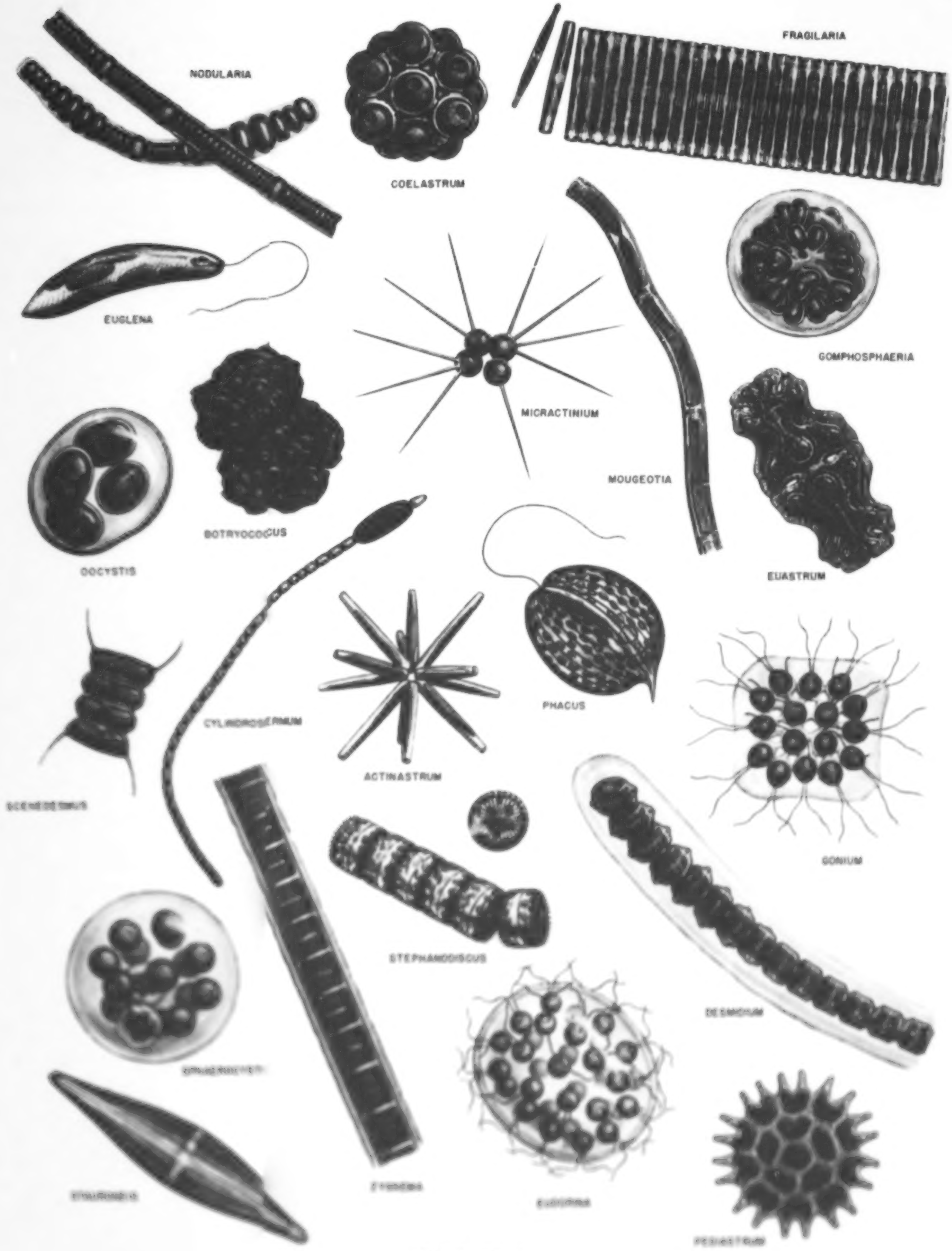

NODULARIA
COELASTRUM
FRAGILARIA
EUGLENA
MICRACTINIUM
MOUGEOTIA
GOMPHOSPHAERIA
BOTRYOCOCCUS
OOCYSTIS
EUASTRUM
CYLINDROSPERMUM
ACTINASTRUM
PHACUS
SCENEDESMUS
GONIUM
STEPHANODISCUS
DESMIDIUM
SPHAEROCYSTIS
STAURONEIS
ZYGNEMA
EUDORINA
PEDIASTRUM

PLATE I

PLATE I

PLANKTON ALGAE IN LAKES AND RESERVOIRS

Species Names	*Linear Magnifications*
Actinastrum gracillimum	1000
Botryococcus braunii	1000
Coelastrum microporum	500
Cylindrospermum stagnale	250
Desmidium grevillei	250
Euastrum oblongum	500
Eudorina elegans	250
Euglena gracilis	1000
Fragilaria capucina	1000
Gomphosphaeria aponina	1500
Gonium pectorale	500
Micractinium pusillum	1000
Mougeotia scalaris	250
Nodularia spumigena	500
Oocystis borgei	1000
Pediastrum boryanum	125
Phacus pleuronectes	500
Scenedesmus quadricauda	1000
Sphaerocystis schroeteri	500
Stauroneis phoenicenteron	500
Stephanodiscus hantzschii	1000
Zygnema sterile	250

ATTACHED ALGAE

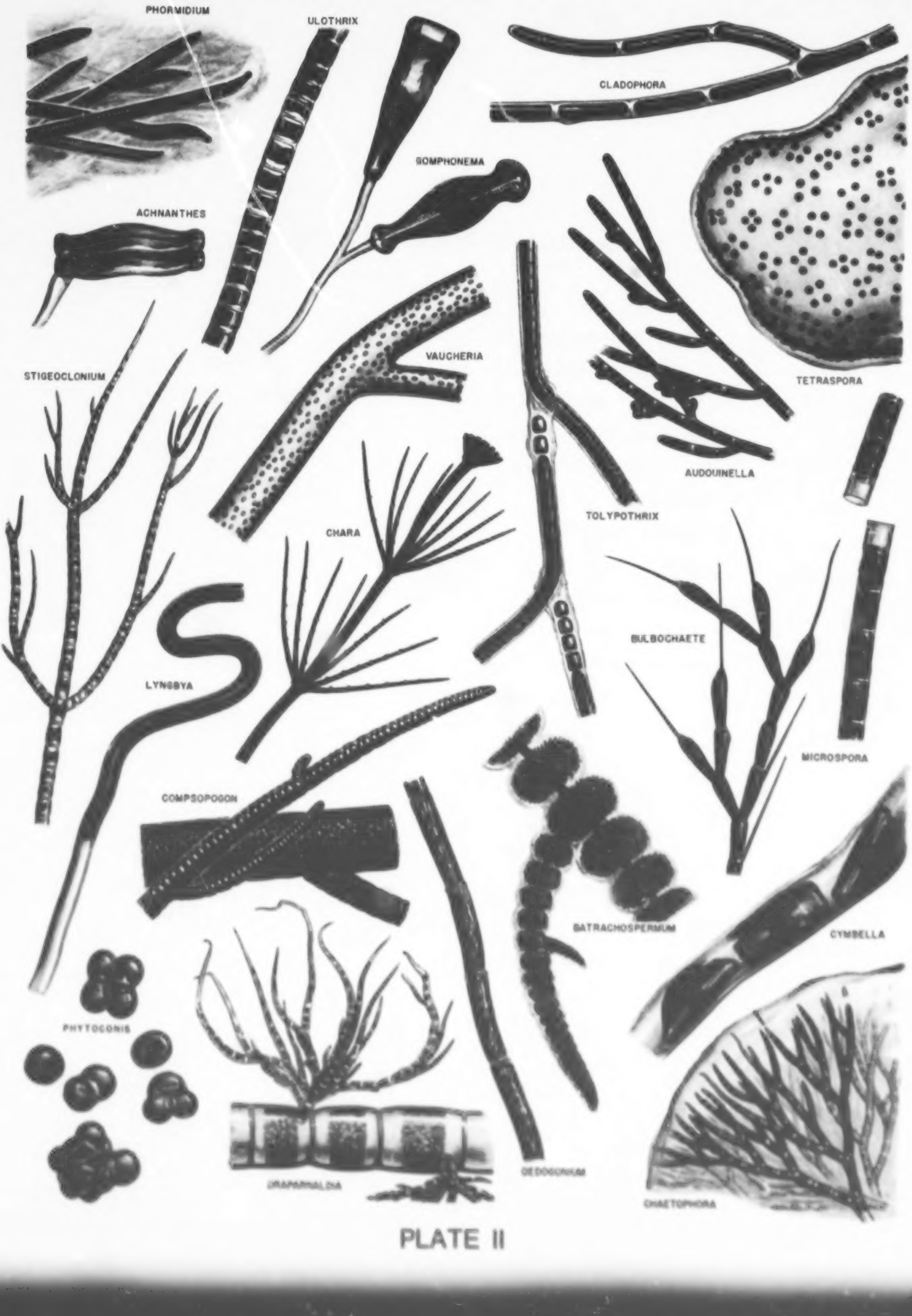

PHORMIDIUM
ULOTHRIX
CLADOPHORA
GOMPHONEMA
ACHNANTHES
VAUCHERIA
STIGEOCLONIUM
TETRASPORA
AUDOUINELLA
CHARA
TOLYPOTHRIX
LYNGBYA
BULBOCHAETE
MICROSPORA
COMPSOPOGON
BATRACHOSPERMUM
CYMBELLA
PHYTOCONIS
DRAPARNALDIA
OEDOGONIUM
CHAETOPHORA

PLATE II

PLATE II

ATTACHED ALGAE

Species Names	*Linear Magnifications*
Achnanthes microcephala	1500
Audouinella violacea	250
Batrachospermum moniliforme	3
Bulbochaete insignis	125
Chaetophora elegans	250
Chara globularis	4
Cladophora crispata	125
Compsopogon coeruleus	125
Cymbella prostrata	250
Draparnaldia glomerata	125
Gomphonema geminatum	250
Lyngbya lagerheimii	1000
Microspora amoena	250
Oedogonium suecicum	500
Phormidium uncinatum	250
Phytoconis botryoides	1000
Stigeoclonium lubricum	250
Tetraspora gelatinosa	125
Tolypothrix tenuis	500
Ulothrix zonata	250
Vaucheria sessilis	125

CLEAN WATER ALGAE

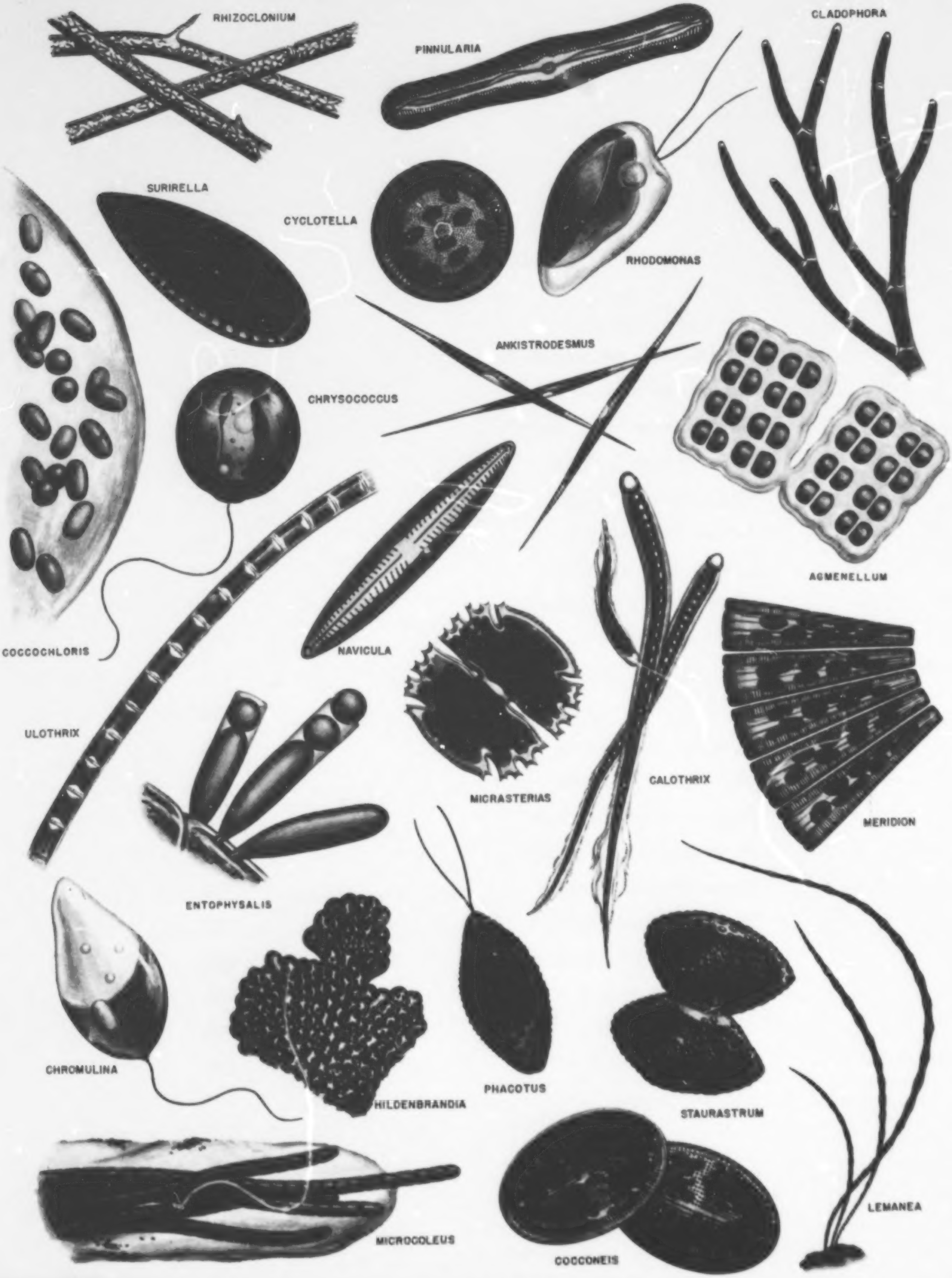

RHIZOCLONIUM
PINNULARIA
CLADOPHORA
SURIRELLA
CYCLOTELLA
RHODOMONAS
ANKISTRODESMUS
CHRYSOCOCCUS
AGMENELLUM
COCCOCHLORIS
NAVICULA
ULOTHRIX
MICRASTERIAS
CALOTHRIX
MERIDION
ENTOPHYSALIS
CHROMULINA
PHACOTUS
HILDENBRANDIA
STAURASTRUM
LEMANEA
MICROCOLEUS
COCCONEIS

PLATE III

PLATE III

CLEAN WATER ALGAE

Species Names	Linear Magnifications
Agmenellum quadriduplicatum, glauca type	250
Ankistrodesmus falcatus var. acicularis	1000
Calothrix parietina	500
Chromulina rosanoffi	4000
Chrysococcus rufescens	4000
Cladophora glomerata	100
Coccochloris stagnina	1000
Cocconeis placentula	1000
Cyclotella bodanica	500
Entophysalis lemaniae	1500
Hildenbrandia rivularis	500
Lemanea annulata	1
Meridion circulare	1000
Micrasterias truncata	250
Microcoleus subtorulosus	500
Navicula gracilis	1000
Phacotus lenticularis	2000
Pinnularia nobilis	250
Rhizoclonium hieroglyphicum	250
Rhodomonas lacustris	3000
Staurastrum punctulatum	1000
Surirella splendida	500
Ulothrix aequalis	250

FRESH WATER POLLUTION ALGAE

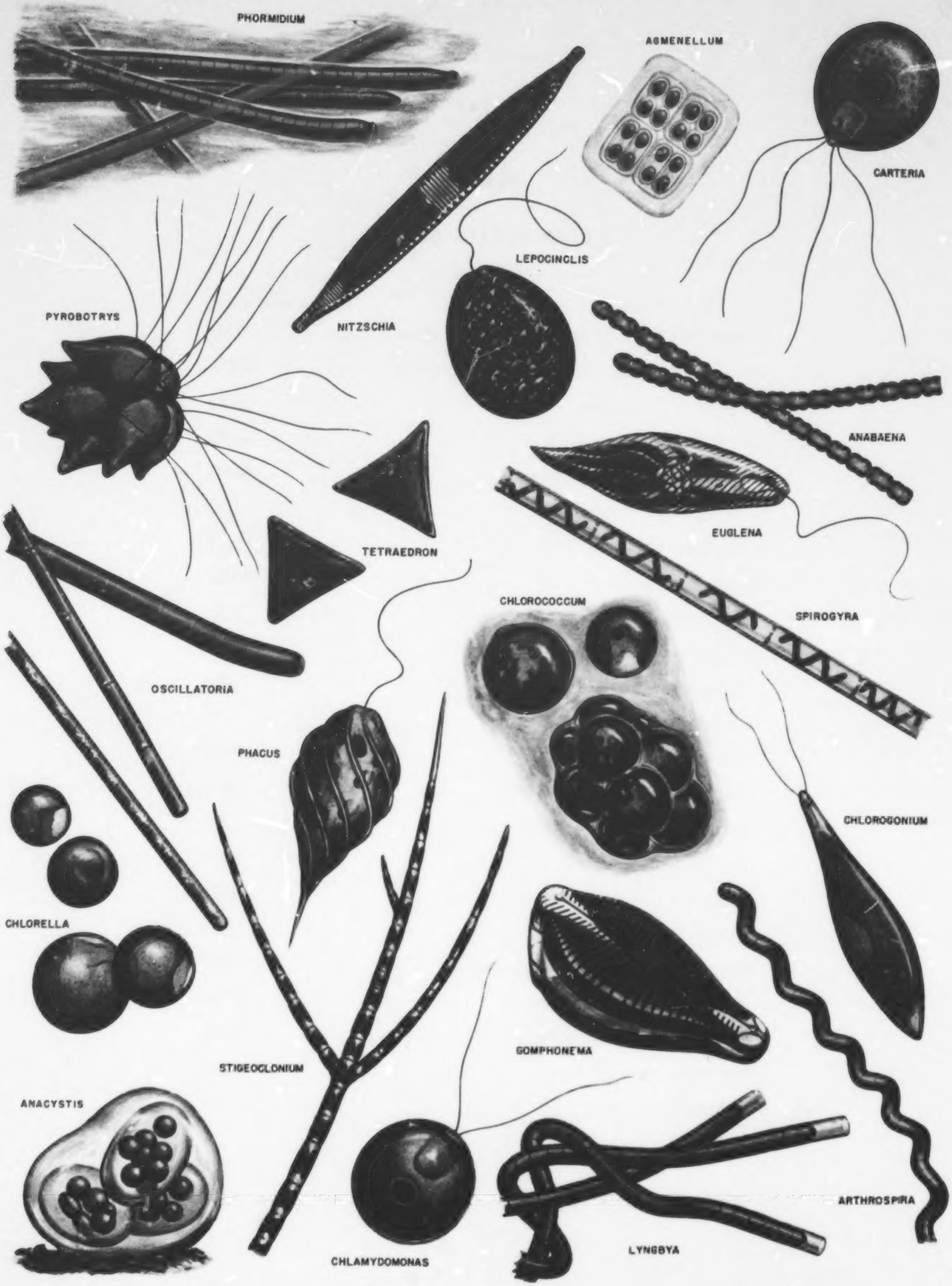

PHORMIDIUM
AGMENELLUM
CARTERIA
LEPOCINCLIS
PYROBOTRYS
NITZSCHIA
ANABAENA
EUGLENA
TETRAEDRON
CHLOROCOCCUM
SPIROGYRA
OSCILLATORIA
PHACUS
CHLOROGONIUM
CHLORELLA
GOMPHONEMA
STIGEOCLONIUM
ANACYSTIS
ARTHROSPIRA
LYNGBYA
CHLAMYDOMONAS

PLATE IV

PLATE IV

FRESH WATER POLLUTION ALGAE

Species Names	*Linear Magnifications*
Agmenellum quadriduplicatum, tenuissima type	1000
Anabaena constricta	500
Anacystis montana	1000
Arthrospira jenneri	1000
Carteria multifilis	2000
Chlamydomonas reinhardi	1500
Chlorella vulgaris	2000
Chlorococcum humicola	1000
Chlorogonium euchlorum	1500
Euglena viridis	1000
Gomphonema parvulum	3000
Lepocinclis texta	500
Lyngbya digueti	1000
Nitzschia palea	2000
Oscillatoria chlorina (top)	1000
Oscillatoria putrida (middle)	1000
Oscillatoria lauterbornii (bottom)	1000
Phacus pyrum	1500
Phormidium autumnale	500
Pyrobotrys stellata	1500
Spirogyra communis	250
Stigeoclonium tenue	500
Tetraedron muticum	1500

ESTUARINE POLLUTION ALGAE

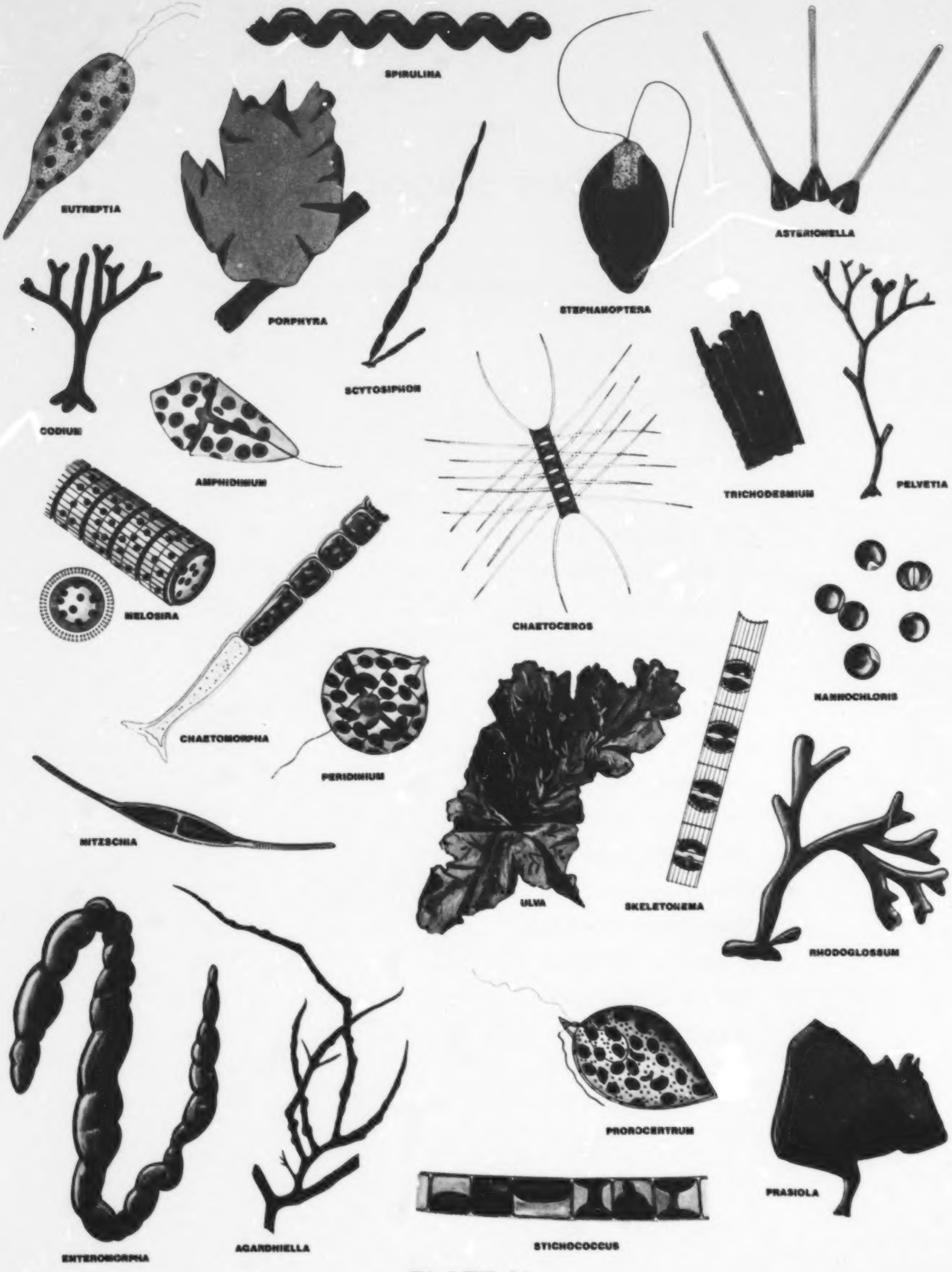

SPIRULINA
EUTREPTIA
PORPHYRA
STEPHANOPTERA
ASTERIONELLA
SCYTOSIPHON
CODIUM
AMPHIDINIUM
TRICHODESMIUM
PELVETIA
CHAETOCEROS
MELOSIRA
CHAETOMORPHA
PERIDINIUM
NANNOCHLORIS
NITZSCHIA
ULVA
SKELETONEMA
RHODOGLOSSUM
PROROCENTRUM
PRASIOLA
ENTEROMORPHA
AGARDHIELLA
STICHOCOCCUS

PLATE V

PLATE V

ESTUARINE POLLUTION ALGAE

Species Names	*Linear Magnifications*
Agardhiella tenera	2
Amphidinium fusiforme	1500
Asterionella japonica	500
Chaetoceros decipiens	750
Chaetomorpha aerea	125
Codium fragile	0.25
Enteromorpha intestinalis	0.25
Eutreptia viridis	750
Melosira sulcata	500
Nannochloris atomus	2500
Nitzschia closterium	500
Pelvetia fastigiata	0.25
Peridinium trochoideum	1000
Porphyra atropurpurea	0.25
Prasiola stipitata	10
Prorocentrum micans	750
Rhodoglossum affine	0.5
Scytosiphon lomentaria	0.25
Skeletonema costatum	500
Spirulina major	2500
Stephanoptera gracilis	2000
Stichococcus marinus	125
Trichodesmium erythraeum	2000
Ulva lactuca	0.5

SEWAGE POND ALGAE

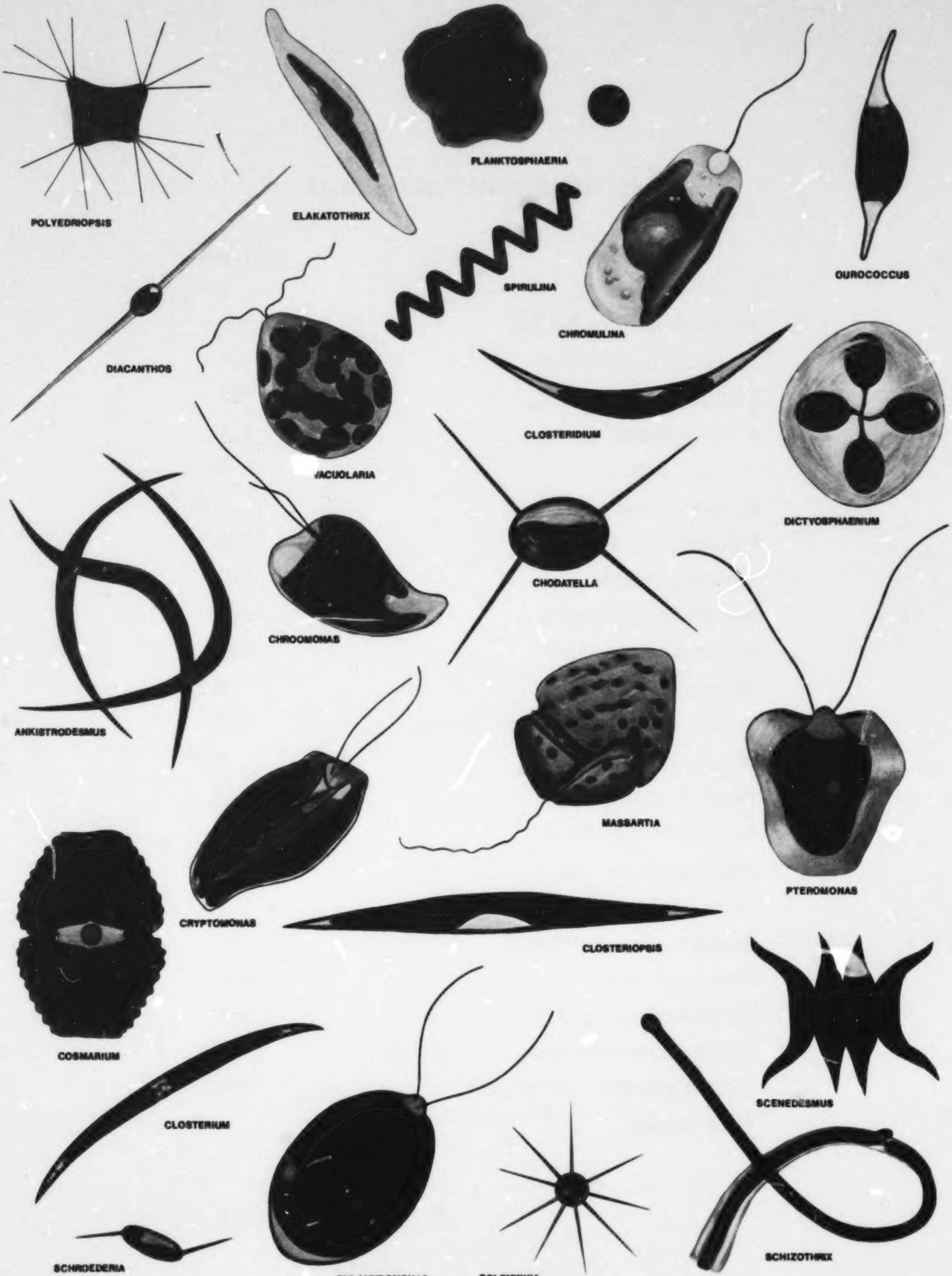

POLYEDRIOPSIS
ELAKATOTHRIX
PLANKTOSPHAERIA
SPIRULINA
CHROMULINA
OUROCOCCUS
DIACANTHOS
VACUOLARIA
CLOSTERIDIUM
DICTYOSPHAERIUM
CHODATELLA
CHROOMONAS
ANKISTRODESMUS
MASSARTIA
PTEROMONAS
CRYPTOMONAS
CLOSTERIOPSIS
COSMARIUM
SCENEDESMUS
CLOSTERIUM
SCHROEDERIA
CHLAMYDOMONAS
GOLENKINIA
SCHIZOTHRIX

PLATE VI

PLATE VI

SEWAGE POND ALGAE

Species Names	*Linear Magnifications*
Ankistrodesmus falcatus	1000
Chlamydomonas pertusa	2000
Chodatella quadriseta	3000
Chromulina vagans	2000
Chroomonas caudata	2500
Closteriopsis brevicula	250
Closterium acutum	500
Cosmarium botrytis	500
Cryptomonas cylindrica	2000
Diacanthos belenophorus	750
Dictyosphaerium ehrenbergianum	1000
Elakatothrix gelatinosa	1000
Golenkinia radiata	500
Massartia vorticella	1500
Ourococcus bicaudatus	1500
Planktosphaeria gelatinosa	500
Polyedriopsis spinulosa	500
Pteromonas angulosa	1250
Scenedesmus dimorphus	1500
Schizothrix calcicola	2000
Schroederia setigera	250
Spirulina subtilissima	4000
Vacuolaria novo-munda	1250

TASTE AND ODOR ALGAE

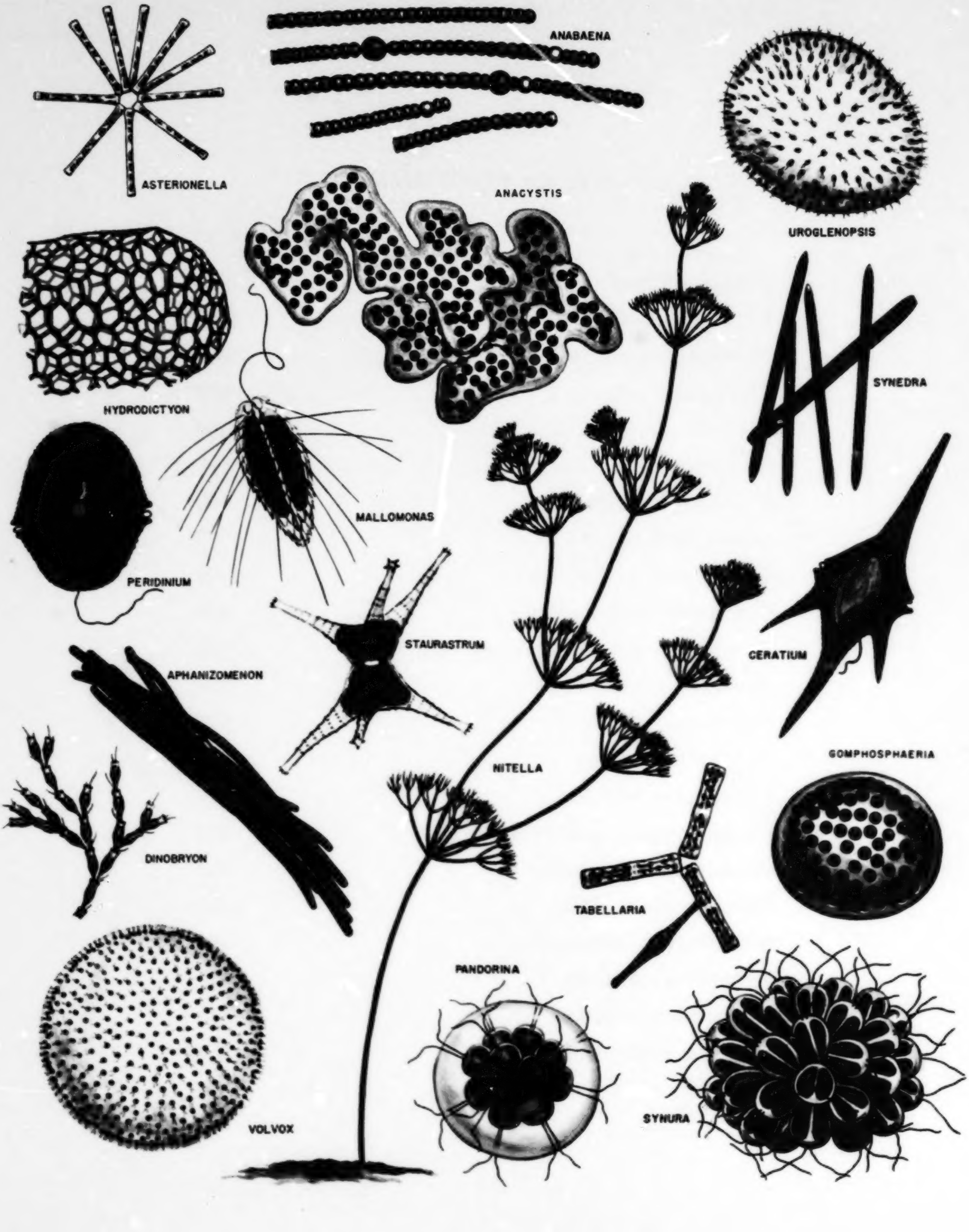

ASTERIONELLA
ANABAENA
UROGLENOPSIS
ANACYSTIS
HYDRODICTYON
SYNEDRA
MALLOMONAS
PERIDINIUM
STAURASTRUM
APHANIZOMENON
CERATIUM
NITELLA
GOMPHOSPHAERIA
DINOBRYON
TABELLARIA
PANDORINA
VOLVOX
SYNURA

PLATE VII

PLATE VII

TASTE AND ODOR ALGAE

Species Names	*Linear Magnifications*
Anabaena planctonica	250
Anacystis cyanea	250
Aphanizomenon flos-aquae	250
Asterionella gracillima	250
Ceratium hirundinella	250
Dinobryon divergens	250
Gomphosphaeria lacustris, kuetzingianum type	500
Hydrodictyon reticulatum	10
Mallomonas caudata	500
Nitella gracilis	1
Pandorina morum	500
Peridinium cinctum	500
Staurastrum paradoxum	500
Synedra ulna	250
Synura uvella	500
Tabellaria fenestrata	250
Uroglenopsis americana	125
Volvox aureus	125

FILTER AND SCREEN CLOGGING ALGAE

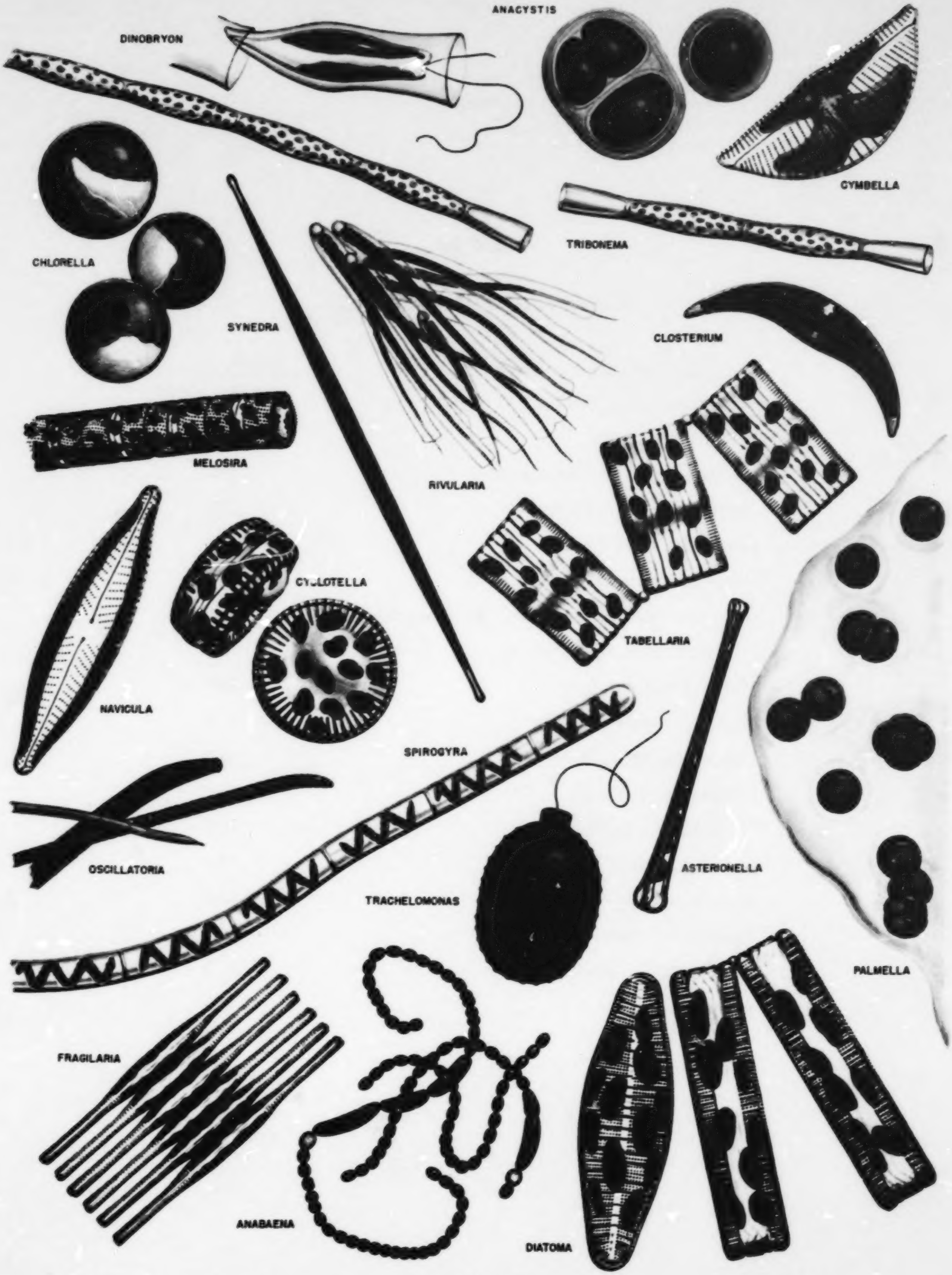

DINOBRYON
ANACYSTIS
CYMBELLA
CHLORELLA
TRIBONEMA
SYNEDRA
CLOSTERIUM
MELOSIRA
RIVULARIA
CYCLOTELLA
TABELLARIA
NAVICULA
SPIROGYRA
ASTERIONELLA
OSCILLATORIA
TRACHELOMONAS
PALMELLA
FRAGILARIA
ANABAENA
DIATOMA

PLATE VIII

PLATE VIII

FILTER AND SCREEN CLOGGING ALGAE

Species Names	Linear Magnifications
Anabaena flos-aquae	500
Anacystis dimidiata	1000
Asterionella formosa	1000
Chlorella pyrenoidosa	5000
Closterium moniliferum	250
Cyclotella meneghiniana	1500
Cymbella ventricosa	1500
Diatoma vulgare	1500
Dinobryon sertularia	1500
Fragilaria crotonensis	1000
Melosira granulata	1000
Navicula graciloides	1500
Oscillatoria princeps (top)	250
Oscillatoria chalybea (middle)	250
Oscillatoria splendida (bottom)	500
Palmella mucosa	1000
Rivularia dura	250
Spirogyra porticalis	125
Synedra acus	500
Tabellaria flocculosa	1500
Trachelomonas crebea	1500
Tribonema bombycinum	500

APPENDIX

Key to Fresh Water Algae
Common in Water Supplies and in Polluted Waters

Beginning with "1a" and "1b," choose one of the two contrasting statements and follow this procedure with the "a" and "b" statements of the number given at the end of the chosen statement. Continue until the name of the alga is given instead of another key number. (Where recent changes in names of algae have been made, the new name is given followed by the old name in brackets.)

1a.	Plastid (separate color body) absent; complete protoplast pigmented; generally blue-green; iodine starch test* negative (blue-green algae)	4
1b.	Plastid or plastids present; parts of protoplast free of some or all pigments; generally green, brown, red, etc., but not blue-green; iodine starch test* positive or negative	2
2a.	Cell wall permanently rigid (never showing evidence of collapse), and with regular pattern of fine markings (striations, etc.); plastids brown-to-green; iodine starch test* negative; flagella absent; wall of two essentially similar halves, one placed over the other as a cover (diatoms)	75
2b.	Cell wall is present, capable of sagging, wrinkling, bulging, or rigidity, depending on existing turgor pressure of cell protoplast; regular pattern of fine markings on wall generally absent; plastids green, red, brown, etc.; iodine starch test* positive or negative; flagella present or absent; cell wall continuous and generally not of two parts	3
3a.	Cell or colony motile; flagella present (often not readily visible); anterior and posterior ends of cell different from one another in contents and often in shape (flagellate algae)	198
3b.	Non-motile; true flagella absent; ends of cells often not differentiated (green algae and associated forms)	262

Blue-Green Algae

4a.	Cells in filaments (or much elongated to form a thread)	5
4b.	Cells not in (or as) filaments	61
5a.	Heterocysts present	6
5b.	Heterocysts absent	25
6a.	Heterocyst located at one end of filament	7
6b.	Heterocyst at various locations in filament	15
7a.	Filaments radially arranged in a gelatinous bead	8
7b.	Filaments isolated or irregularly grouped	11
8a.	Akinetes present *(Gloeotrichia)*	9
8b.	Akinetes absent (*Rivularia*)	10
9a.	Gelatinous colony a smooth bead *Gloeotrichia echinulata*	
9b.	Gelatinous colony irregular *Gloeotrichia natans*	
10a.	Cells near the narrow end as long as wide *Rivularia dura*	
10b.	Cells near the narrow end twice as long as wide *Rivularia haematites*	
11a.	Filament gradually narrowed to one end (*Calothrix*)	12
11b.	Filament not gradually narrowed to one end	13
12a.	Cells adjacent to heterocyst wider than heterocyst *Calothrix braunii*	
12b.	Cells adjacent to heterocyst narrower than heterocyst *Calothrix parietina*	
13a.	Heterocysts at both ends; filaments bent *Anabaenopsis*	
13b.	Heterocysts at one end; filaments straight (*Cylindrospermum*)	14
14a.	Heterocysts round *Cylindrospermum muscicola*	
14b.	Heterocysts elongate *Cylindrospermum stagnale*	
15a.	Filaments unbranched or with true branches	16
15b.	Filament with occasional false branches	24
16a.	True branching present; filament all or partly multiseriate *Stigonema minutum*	
16b.	Branching absent; filaments uniseriate	17
17a.	Cross-walls much closer together than width of filament *Nodularia spumigena*	
17b.	Cross-walls at least as far apart as width of filament	18
18a.	Filaments normally in tight parallel clusters; heterocysts and spores cylindric to long oval *Aphanizomenon flos-aquae*	

---

*Add one drop Lugol's (iodine) solution, diluted 1:1 with distilled water. In about 1 min, if positive, starch is stained blue.

18b.	Filaments not in tight parallel clusters; heterocysts and spores often round to oval	19
19a.	Filaments in a common gelatinous mass (*Nostoc*)	20
19b.	Filaments not in a common gelatinous mass (*Anabaena*)	21
20a.	Heterocysts and vegetative cells rounded *Nostoc pruniforme*	
20b.	Heterocysts and vegetative cells oblong *Nostoc carneum*	
21a.	Cells elongate, depressed in the middle; heterocysts rare *Anabaena constricta*	
21b.	Cells rounded; heterocysts common	22
22a.	Heterocysts with lateral extensions *Anabaena planctonica*	
22b.	Heterocysts without lateral extensions	23
23a.	Threads 4-8 microns wide *Anabaena flos-aquae*	
23b.	Threads 8-14 microns wide *Anabaena circinalis*	
24a.	False branches in pairs *Scytonema tolypothricoides*	
24b.	False branches single *Tolypothrix tenuis*	
25a.	Filament or elongated cell attached at one end and with one or more round cells (spores) at the other end *Entophysalis lemaniae*	
25b.	Filament generally not attached at one end; no terminal spores present	26
26a.	Filament with regular spiral form throughout	27
26b.	Filament not spiral or with spiral limited to a portion of filament	30
27a.	Filament septate *Arthrospira jenneri*	
27b.	Filaments not septate (*Spirulina*)	28
28a.	Thread 0.9 micron or less in diameter *Spirulina subtillissima*	
28b.	Thread 1.2 microns or more in diameter	29
29a.	Thread 1.2-1.7 microns in diameter *Spirulina major*	
29b.	Thread 2.0 microns in diameter *Spirulina nordstedtii*	
30a.	Filament aggregates forming conical tufts *Symploca muscorum*	
30b.	Filament aggregates not forming conical tufts	31
31a.	Filament very narrow, only 0.5-2.0 microns wide *Schizothrix calcicola*	
31b.	Filament 3.0-95.0 microns wide	32
32a.	Filaments loosely aggregated or not in clusters	33
32b.	Filaments tightly aggregated and surrounded by a common gelatinous secretion that may be invisible	56
33a.	Filament surrounded by a wall-like sheath that frequently extends beyond the ends of the filament of cells; filament generally without movement	34
33b.	Filament not surrounded by a wall-like sheath; filament may show movement	41
34a.	False branching present *Plectonema tomasiniana*	
34b.	False branches absent	35
35a.	Cells separated from one another by a space *Johannesbaptistia*	
35b.	Cells in contact with adjacent cells (*Lyngbya*)	36
36a.	Threads in part forming spirals *Lyngbya lagerheimii*	
36b.	Straight or bent but not in spirals	37
37a.	Threads colored yellowish to brown	38
37b.	Sheaths colorless	39
38a.	Cells rounded *Lyngbya ochracea*	
38b.	Cells short discs *Lyngbya aestuarii*	
39a.	Cells constricted at the joints *Lyngbya putealis*	
39b.	Cells not constricted at the joints	40
40a.	Sheath very thick *Lyngbya versicolor*	
40b.	Sheath very thin *Lyngbya digueti*	
41a.	All filaments short, with less than 20 cells; one or both ends of filament sharp pointed *Raphidiopsis*	
41b.	Filaments long with more than 20 cells; filaments commonly without sharp-pointed ends (*Oscillatoria*)	42
42a.	Cells very short, generally less than one-third the thread diameter	43
42b.	Cells generally one-half as long to longer than thread diameter	46
43a.	Cross walls constricted *Oscillatoria ornata*	
43b.	Cross walls not constricted	44
44a.	Ends of mature threads curved	45
44b.	Ends of mature threads straight *Oscillatoria limosa*	
45a.	Threads 10-14 microns thick *Oscillatoria curviceps*	
45b.	Threads 16-60 microns thick *Oscillatoria princeps*	
46a.	Threads appearing red to purplish *Oscillatoria rubescens*	
46b.	Threads yellow-green to blue-green	47
47a.	Threads blue-green	48
47b.	Threads yellow-green	53
48a.	Cells ½-2 times as long as thread diameter.	49
48b.	Cells 2-3 times as long as thread diameter.	55
49a.	Cell walls between cells thick and transparent *Oscillatoria pseudogeminata*	
49b.	Cell walls thin, appearing as a dark line	50
50a.	Ends of thread straight *Oscillatoria agardhii*	
50b.	Ends of mature threads curved	51
51a.	Prominent granules present especially at both ends of each cell *Oscillatoria tenuis*	

51b. Cells without prominent granules 52

52a. Cross walls constricted .... *Oscillatoria chalybea*

52b. Cross walls not constricted .... *Oscillatoria formosa*

53a. Cells 4-7 times as long as thread diameter .... *Oscillatoria putrida*

53b. Cells less than 4 times as long as the thread diameter 54

54a. Prominent granules (pseudovacuoles) in center of each cell .... *Oscillatoria lauterbornii*

54b. No prominent granules in center of cells .... *Oscillatoria chlorina*

55a. End of thread long tapering .... *Oscillatoria splendida*

55b. End of thread not tapering .... *Oscillatoria amphibia*

56a. Filaments arranged in a tight, essentially parallel bundle ..... *Microcoleus subterulosus*

56b. Filaments arranged in irregular fashion, often forming a mat .... *(Phormidium)* 57

57a. Ends of some threads with a rounded swollen "cap" cell 58

57b. Ends of all threads without a "cap" cell... 60

58a. Cells quadrate ..... *Phormidium autumnale*

58b. Cells much shorter than broad 59

59a. Ends of some threads with round cap and abruptly bent ..... *Phormidium uncinatum*

59b. Ends of some threads with conical cap and straight .... *Phormidium subfuscum*

60a. Threads 3-5 microns in width .... *Phormidium inundatum*

60b. Threads 5-12 microns in width .... *Phormidium retzii*

61a. Cells in a regular pattern of parallel rows, forming a plate .... *(Agmenellum quadriduplicatum)* 62

61b. Cells not regularly arranged to form a plate 63

62a. Cell diameter 1.3-2.2 microns...... *Agmenellum quadriduplicatum, tenuissima* type

62b. Cell diameter 3-5 microns .... *Agmenellum quadriduplicatum, glauca* type

63a. Cells regularly arranged near surface of a spherical gelatinous bead 64

63b. Gelatinous bead, if present, not spherical.. 68

64a. Cells ovate to heart-shaped; connected to center of bead by colorless stalks .... *(Gomphosphaeria)* 65

64b. Cells round; without gelatinous stalks..... *(Gomphosphaeria* [Coelosphaerium type]) 65

65a. Cells with pseudovacuoles .... *Gomphosphaeria wichurae*

65b. Cells without pseudovacuoles 66

66a. Cells 2-4 microns diameter .... *(Gomphosphaeria lacustris)* 67

66b. Cells 4-15 microns diameter .... *Gomphosphaeria aponina*

67a. Cells spherical .... *Gomphosphaeria lacustris, kuetzingianum* type

67b. Cells ovate .... *Gomphosphaeria lacustris, collinsii* type

68a. Cells attached .... *Dermocarpa*

68b. Cells unattached 69

69a. Cells cylindric-oval .. *Coccochloris stagnina*

69b. Cells spherical 70

70a. Two or more distinct layers of gelatinous sheath around each cell or cell cluster..... .... *(Anacystis* [*Gloeocapsa*]*)* 72

70b. Gelatinous sheath around cells not distinctly layered 71

71a. Cells isolated or in colonies of 2-32 cells.. .... *(Anacystis* [*Chroococcus*]*)* 72

71b. Cells in colonies of many cells .... *(Anacystis* [*Microcystis*]*)* 72

72a. Cell containing pseudovacuoles .... *Anacystis cyanea*

72b. Cell not containing pseudovacuoles 73

73a. Cell 2-6 microns diameter; sheath often colored .... *Anacystis montana*

73b. Cell 6-50 microns diameter; sheath colorless 74

74a. Cell 6-12 microns diameter; cells in colonies are mostly spherical .... *Anacystis thermalis*

74b. Cell 12-50 microns diameter; cells in colonies are often irregular. *Anacystis dimidiata*

Diatoms

75a. Transverse wall markings not in one or two longitudinal rows; front (valve) view generally circular in outline; markings, if present, radial in arrangement; cells may form a filament .... (centric diatoms) 76

75b. Front (valve) view elongate, not circular; transverse wall markings in one or two longitudinal rows; cells if grouped, not forming a filament but a ribbon, star, etc. .... (pennate diatoms) 107

76a. Cells pillow shaped in girdle view with a blunt process at each corner .... *Biddulphia laevis*

76b. Cells without blunt processes 77

77a. Cells very long, cylindrical in girdle view, with a long spine at each end............ *(Rhizosolenia)* 78

77b. Cells a disc or short cylinder in girdle view with no long spine at each end of side.... 79

78a. Setae shorter than cell length .... *Rhizosolenia eriensis*

78b. Setae longer than cell length .... *Rhizosolenia gracilis*

79a. Cells in persistent filaments with valve faces in contact; therefore, cells commonly seen in side (girdle) view ....*(Melosira)* 80

79b. Cells isolated or in fragile filaments, often seen in front (valve) view 88

80a.	Distinct pores on valve mantle (shoulder) ... *Melosira binderana*	
80b.	No distinct pores on valve mantle (shoulder)	81
81a.	No visible ornamentation ... *Melosira varians*	
81b.	Ornamentation visible	82
82a.	Terminal cells with long spines	83
82b.	Terminal cells without long spines	84
83a.	Diameter 5-21 microns ... *Melosira granulata*	
83b.	Diameter 3-5 microns ... *Melosira granulata* var. *angustissima*	
84a.	Sulcus (groove) angular at base ... *Melosira ambigua*	
84b.	Sulcus (groove) not angular at base	85
85a.	Semi-cells shorter than wide ... *Melosira distans* var. *alpigena*	
85b.	Semi-cells about as long as wide	86
86a.	With robust short spines ... *Melosira italica*	
86b.	With fine teeth	87
87a.	Sulcus distinctly acute-angled ... *Melosira crenulata*	
87b.	Sulcus not distinctly acute-angled ... *Melosira islandica*	
88a.	Radial markings (striations), in valve view, extending from center to margin; short marginal spines sometimes present in valve view	89
88b.	Area of prominent markings, in valve view, limited to about outer half of circle; marginal spines generally absent ... (*Cyclotella*)	90
89a.	Radiate hyaline areas on valve view ... (*Stephanodiscus*)	99
89b.	No radial hyaline areas on valve view ... (*Coscinodiscus*)	106
90a.	Cells with marginal spines ... *Cyclotella pseudostelligera*	
90b.	Cells without marginal spines	91
91a.	Central area with 3-4 round, raised spots ... *Cyclotella ocellata*	
91b.	Central area without such ocelli	92
92a.	Central area with star-shaped lines around a central dot ... *Cyclotella stelligera*	
92b.	Central area otherwise	93
93a.	Cells small; 4-10 microns diameter	94
93b.	Cells larger; 10-80 microns diameter	95
94a.	Cells in chains; single ocellus in central area ... *Cyclotella atomus*	
94b.	Cells all isolated; no ocellus in central area ... *Cyclotella glomerata*	
95a.	Central area clear ... *Cyclotella meneghiniana*	
95b.	Central area with markings	96
96a.	Circular shadow line passes through the costae ... *Cyclotella striata*	
96b.	No circular shadow line	97
97a.	Central area with punctae or short lines ... *Cyclotella kutzingiana*	
97b.	Central area with fine radial striae	98
98a.	A puncta at inner end of several shortened marginal costae ... *Cyclotella bodanica*	
98b.	No puncta at inner end of several marginal costae ... *Cyclotella comta*	
99a.	Cell diameter 4-30 microns	100
99b.	Cell diameter 30-80 microns	104
100a.	Prominent rib-like structures over outer third of cell ... *Stephanodiscus dubius*	
100b.	No prominent rib-like structures	101
101a.	Spine at end of each striation ... *Stephanodiscus tenuis*	
101b.	Spines not as above	102
102a.	Spines alternating with striae ... *Stephanodiscus hantzschii*	
102b.	Spines not as above	103
103a.	Girdle view with two transverse bands ... *Stephanodiscus binderanus*	
103b.	Girdle view without transverse bands ... *Stephanodiscus astraea* var. *minutula*	
104a.	Outer punctae of striae 12 in 10 microns ... *Stephanodiscus astraea*	
104b.	Outer punctae of striae 16 in 10 microns	105
105a.	Cell diameter 30-60 microns ... *Stephanodiscus niagarae*	
105b.	Cell diameter 72-80 microns ... *Stephanodiscus niagarae* var. *magnifica*	
106a.	Surface slightly undulate; markings polygonal ... *Coscinodiscus rothii*	
106b.	Surface flat; markings angular with central dots ... *Coscinodiscus denarius*	
107a.	Cell longitudinally symmetrical in valve view	108
107b.	Cell longitudinally unsymmetrical (two sides unequal in shape), at least in valve view	188
108a.	Raphe at or near the edge of the valve	109
108b.	Raphe or pseudoraphe median or submedian	124
109a.	Cells lying side by side in colonies ... *Bacillaria paradoxa*	
109b.	Cells isolated or in twos	110
110a.	Valve face transversely undulate ... *Cymatopleura solea*	
110b.	Valve face not transversely undulate	111
111a.	Marginal, keeled raphe areas lie opposite one another on the two valves ... *Hantzschia amphioxys*	
111b.	Marginal, keeled raphe areas lie diagonal to one another on the two valves ... (*Nitzschia*)	112
112a.	Valve long-pointed, spine-like ... *Nitzschia acicularis*	
112b.	Valve not long-pointed and spine-like	113
113a.	Valve axis sigmoid	114
113b.	Valve axis not sigmoid	116
114a.	Cell 20-40 microns long ... *Nitzschia parvula*	
114b.	Cell more than 40 microns long	115
115a.	Cell 50-70 microns long ... *Nitzschia sigma*	
115b.	Cell 160-500 microns long ... *Nitzschia sigmoidea*	
116a.	Carinal dots extended far across the valve ... *Nitzschia denticula*	

116b. Carinal dots not extended far across the valve 117

117a. Cells in star-shaped colonies .... *Nitzschia holsatica*

117b. Cells not in star-shaped colonies 118

118a. Keel only slightly excentric .... *Nitzschia dissipata*

118b. Keel distinctly excentric 119

119a. Cell distinctly pulled in at the middle .... *Nitzschia linearis*

119b. Cell not distinctly pulled in at the middle .. 120

120a. Cell with longitudinal fold 121

120b. Cell without longitudinal fold 122

121a. Cell 6-9 microns broad .. *Nitzschia hungarica*

121b. Cell 16-35 microns broad .... *Nitzschia tryblionella*

122a. Striae 15-17 in 10 microns .... *Nitzschia amphibia*

122b. Striae more than 25 in 10 microns 123

123a. Striae 28-30 in 10 microns; cells elliptical-lanceolate .... *Nitzschia fonticula*

123b. Striae 35-40 in 10 microns; cells linear-lanceolate .... *Nitzschia palea*

124a. Cell transversely symmetrical in valve view 125

124b. Cell transversely unsymmetrical (two ends unequal in shape or size), at least in valve view 175

125a. Cell round-oval in valve view; not more than twice as long as wide ..... *(Cocconeis)* 126

125b. Cell elongate, more than twice as long as wide 127

126a. Wall markings (striae) 18-20 in 10 microns .... *Cocconeis pediculus*

126b. Wall markings (striae) 23-25 in 10 microns .... *Cocconeis placentula*

127a. Cell flat; girdle face wide, valve face narrow .... *(Tabellaria)* 128

127b. Girdle and valve faces about equal in width 129

128a. Girdle face less than one-fourth as wide as long .... *Tabellaria fenestrata*

128b. Girdle face more than one-half as wide as long .... *Tabellaria flocculosa*

129a. Cell with several markings (septa) extending without interruption across the valve face; no marginal line of pores present *(Diatoma)* 130

129b. Cross-markings (striations or costae) on valve surface, either interrupted by longitudinal space (pseudoraphe), line (raphe), or line of pores (carinal dots) 132

130a. Cells 2-4 microns wide . *Diatoma elongatum*

130b. Cells 4-13 microns wide 131

131a. Cells 4-8 microns wide .... *Diatoma anceps*

131b. Cells 10-13 microns wide .. *Diatoma vulgare*

132a. Cells attached side by side to form a ribbon of several-to-many cells .... *(Fragilaria)* 133

132b. Cells isolated or in pairs 138

133a. Cells attached at middle portion only .... *Fragilaria crotonensis*

133b. Cells attached along entire length 134

134a. Central area clear ...... *Fragilaria capucina*

134b. Central area not clear; has striations 135

135a. Striae coarse 136

135b. Striae fine 137

136a. Valves much inflated at center .... *Fragilaria leptostauron*

136b. Valves not inflated at center .... *Fragilaria pinnata*

137a. Striae very short; cells 3-5 microns wide .. .. *Fragilaria brevistriata*

137b. Striae long; cells 5-12 microns wide .... *Fragilaria construens*

138a. Cell narrow, linear, often narrowed to both ends; true raphe absent .... *(Synedra)* 139

138b. Cell commonly "boat" shaped in valve view; true raphe present 147

139a. Cell width 1-2 microns ..... *Synedra nana*

139b. Cell width 2-10 microns 140

140a. Cell width 2-5 microns 141

140b. Cell width 5-10 microns 144

141a. Central clear area on one side of valve only .... *Synedra vaucheriae*

141b. No clear area on one side of center of valve only 142

142a. Central clear area present; striae almost continuous 143

142b. Central clear area absent; striae short .... *Synedra tabulata*

143a. Cell length about 500 microns .... *Synedra acus* var. *angustissima*

143b. Cell length 40-200 microns .... *Synedra acus* var. *radians*

144a. Valves linear .... *Synedra capitata*

144b. Valves lanceolate to linear-lanceolate 145

145a. Valves narrow lanceolate; striae 12-14 in 10 microns .... *Synedra acus*

145b. Valves linear-lanceolate; striae not 12-14 in 10 microns 146

146a. Large clear refractive central area; ends generally capitate ...... *Synedra pulchella*

146b. Large clear non-refractive central area; ends non-capitate .... *Synedra ulna*

147a. Cell longitudinally unsymmetrical in girdle view; sometimes with attachment stalk ... . *(Achnanthes)* 148

147b. Cell symmetrical in girdle as well as valve view; generally not attached 150

148a. Valves constricted toward poles .... *Achnanthes microcephala*

148b. Valves gradually tapering toward the poles 149

149a. Striations pronounced .... *Achnanthes lanceolata*

149b. Striations fine ... *Achnanthes minutissima*

150a. Area without striations extending as a transverse belt around middle of cell .... *Stauroneis phoenicenteron*

150b. No continuous clear belt around middle of cell 151

151a. Cell with coarse transverse markings (costae), which appear as solid lines even under high magnification .... *(Pinnularia)* 152

151b. Cell with fine transverse markings (striae), which appear as lines of dots under high magnification 153

152a. Cell 5-6 microns broad .... *Pinnularia subcapitata*

152b. Cell 34-50 microns broad .... *Pinnularia nobilis*

153a. Girdle view hour-glass shaped; valves with median longitudinal keel (extension) .... *Amphiprora alata*

153b. Girdle view not hour-glass shaped; valves without median longitudinal keel 154

154a. Longitudinal black spaces extending across striations 155

154b. No longitudinal black spaces extending across striations 157

155a. Longitudinal black spaces wavy .... *Anomoeoneis exilis*

155b. Longitudinal black spaces straight 156

156a. Longitudinal black spaces near margin .... *Caloneis*

156b. Longitudinal black spaces near raphe: central nodules with pair of extensions along each side of raphe ...... *Diploneis smithii*

157a. Raphe and valve sigmoid 158

157b. Raphe and valve not sigmoid 160

158a. Valve striae forming transverse and longitudinal rows .... *(Gyrosigma)* 159

158b. Valve striae forming transverse and oblique rows .... *Pleurosigma delicatulum*

159a. Cell length 150-240 microns .... *Gyrosigma attenuatum*

159b. Cell length 80-120 microns .... *Gyrosigma kutzingii*

160a. Pair of longitudinal extensions of central nodule along sides of raphe .... *Frustulia ovulgaris*

160b. Central nodule without longitudinal extensions .... *(Navicula)* 161

161a. Striae irregularly shortened in central area .... *Navicula mutica*

161b. Striae not irregularly shortened in central area 162

162a. Broad clear lanceolate area over much of valve .... *Navicula confervacea*

162b. No broad clear area over much of valve .. 163

163a. Central area long, rectangular .... *Navicula accomoda*

163b. Central area not long and rectangular 164

164a. Margin of valve undulate .... *Navilcula contenta*

164b. Margin of valve not undulate 165

165a. Short septum at apices of valve .... *Navicula incomposita*

165b. No short septum at apices of valve 166

166a. Central area large, irregularly rectangular .. *Navicula exigua* var. *capitata*

166b. Central area not irregularly rectangular ... 167

167a. Central area strongly widened transversely 168

167b. Central area round, rhombic, lanceolate, or small 169

168a. Valve length less than 25 microns .... *Navicula canalis*

168b. Valve length more than 25 microns .... *Navicula graciloides*

169a. Valve ends distinctly narrowed 170

169b. Valve ends truncate, rounded, or acute ... 172

170a. Valve broadly lanceolate; 5-7 microns ... 171

170b. Valve narrowly lanceolate; width 4-5 microns .... *Navicula notha*

171a. Central area large, rounded; ends not capitate .... *Navicula viridula*

171b. Central area medium sized, irregular; ends capitate .... *Navicula cryptocephala*

172a. Terminal striae more strongly marked than elsewhere .... *Navicula hungarica*

172b. Terminal striae not more strongly marked than elsewhere 173

173a. Valves almost linear .... *Navicula tripunctata*

173b. Valves lanceolate 174

174a. Central area large; valve lanceolate .... *Navicula lanceolata*

174b. Central area small; valve linear-lanceolate .... *Navicula radiosa*

175a. Cells attached together at one end only to form radiating colony ....*(Asterionella)* 176

175b. Cells not forming a loose radiating colony 177

176a. Larger terminal swelling 1½ to 2 times wider than the other .. *Asterionella formosa*

176b. Larger terminal swelling less than 1½ times wider than the other .... *Asterionella gracillima*

177a. Cells in fan-shaped colonies .... *Meridion circulare*

177b. Cells isolated or in pairs 178

178a. Prominent wall markings in addition to striations present just below lateral margins on valve .... *(Surirella)* 179

178b. Wall markings along sides of valve limited to striations 183

179a. Cell width 40-160 microns 180

179b. Cell width 8-30 microns 181

180a. Cell transversely symmetrical .... *Surirella striatula*

180b. Cell transversely unsymmetrical .... *Surirella splendida*

181a. Cell linear, symmetrical .... *Surirella angustata*

181b. Cell wider at one end 182

182a. Longitudinal folds marginal .... *Surirella brightwellii*

182b. Longitudinal folds extend to the center .... *Surirella ovata*

183a. Cell elongate; sides of valve almost parallel except for terminal knobs ... *(Asterionella)* 176

183b. Sides of valve converging toward one end 184

184a. Cells bent in girdle view .... *Rhoicosphenia curvata*

184b. Cells straight in girdle view 185

185a. Longitudinal line crossing striae near both sides of valve .... *Gomphoneis*

185b. No longitudinal line crossing striae near both sides of valve .... *(Gomphonema)* 186

186a. Narrow end enlarged in valve view .... *Gomphonema geminatum*

186b. Narrow end not enlarged in valve view ... 187

187a. Tip of broad end about as wide as tip of narrow end in valve view .... *Gomphonema parvulum*

187b. Tip of broad end much wider than tip of narrow end in valve view .... *Gomphonema olivaceum*

188a. Valve with transverse septa or costae 189

188b. Valve with no transverse septa or costae .. 191

189a. Central portion of raphe "V" shaped .... *(Epithemia)* 190

189b. Central portion of raphe straight .... *Rhopalodia gibba*

190a. Cells 8-15 microns wide; constricted below the recurved capitate poles .... *Epithemia sorex*

190b. Cells 15-18 microns wide; only slightly constricted below the recurved somewhat capitate poles .... *Epithemia turgida*

191a. Convex margin of valve undulate at least near the ends .... *(Eunotia)* 192

191b. Convex margin of valve not undulate 193

192a. Valve arcuate .... *Eunotia lunaris*

192b. Valve linear, only slightly curved .... *Eunotia pectinalis*

193a. Raphe located almost through center of valve .... *(Cymbella)* 194

193b. Raphe excentric; near concave edge of valve .... *Amphora ovalis*

194a. Cell only slightly unsymmetrical .... *Cymbella cesati*

194b. Cell distinctly unsymmetrical 195

195a. Central area with a puncta .... *Cymbella tumida*

195b. Central area without puncta 196

196a. Striations distinctly cross-lined .... *Cymbella prostrata*

196b. Striations not distinctly cross-lined 197

197a. Striae 7-9 in 10 microns; cells 30-100 microns long .... *Cymbella turgida*

197b. Striae 12-18 in 10 microns; cells 10-40 microns long .... *Cymbella ventricosa*

Flagellate Algae

198a. Cell in a loose, rigid, conical sac (lorica); isolated or in a branching colony .... *(Dinobryon)* 199

198b. Case or sac, if present, not conical; colony, if present, not branching 202

199a. Branches diverging, often almost at a right angle .... *Dinobryon divergens*

199b. Branches compact, often almost parallel .. 200

200a. Narrow end of lorica sharp pointed 201

200b. Narrow end of lorica blunt pointed .... *Dinobryon sertularia*

201a. Narrow end drawn out into a stalk .... *Dinobryon stipitatum*

201b. Narrow end diverging at the base .... *Dinobryon sociale*

202a. Cells isolated or in pairs 203

202b. Cells in a colony of four or more cells ... 252

203a. Prominent transverse groove encircles the cell 209

203b. Cell without transverse groove 204

204a. Plastid golden-brown 205

204b. Plastid green, yellow-green, red, or blue-green 215

205a. Anterior end of cell rounded; one flagellum .... *(Chromulina)* 206

205b. Anterior end of cell oblique; two flagella .. 207

206a. Plastid in anterior half of cell; posterior portion of cell attenuate .... *Chromulina rosanoffii*

206b. Plastid almost full length of cell; Posterior portion of cell wide, rounded .... *Chromulina vagans*

207a. Flagella extending from gullet; flagella almost equal in length ...... *(Cryptomonas)* 208

207b. No gullet; flagella very unequal in length .... *Ochromonas*

208a. Cell narrowed to posterior end .... *Cryptomonas cylindrica*

208b. Cell not narrowed to posterior end .... *Cryptomonas erosa*

209a. Cell with prominent projections, rigid, one forward and two or three on posterior end .... *Ceratium hirundinella*

209b. Cell without several rigid, polar projections 210

210a. Portions above and below transverse groove about equal 211

210b. Front portion distinctly larger than posterior portion 214

211a. Cells naked, with no cell wall *Gymnodinium*

211b. Cells with cell wall composed of several plates 212

212a.	Cell wall thin but composed of plates *Glenodinium palustre*	
212b.	Cell wall thick with clearly evident plates *(Peridinium)*	213
213a.	Ends of cells pointed *Peridinium wisconsinense*	
213b.	Ends of cell rounded *Peridinium cinctum*	
214a.	Transverse furrow extends about half way around cell *Hemidinium*	
214b.	Transverse furrow extends all way around cell *Massartia vorticella*	
215a.	Cell with long bristles extending from surface plates *Mallomonas caudata*	
215b.	Cells without bristles and surface plates	216
216a.	Plastids blue-green *Cyanomonas*	
216b.	Plastids green, yellow-green, or red	217
217a.	Cell naked, not covered by wall or lorica or rigid membrane *Dunaliella*	
217b.	Cell covered by wall or loose rigid covering or rigid membrane	218
218a.	Space between protoplast and wall with radial strands of protoplasm *Haematococcus*	
218b.	No radial strands of cytoplasm between protoplast and wall or lorica	219
219a.	Cell protoplast enclosed in loose rigid covering (lorica)	220
219b.	Cell with membrane or wall but no loose rigid covering	225
220a.	Cell with four flagella *Pedinopera*	
220b.	Cell with one or two flagella	221
221a.	Lorica flattened; cell with two flagella *Phacotus lenticularis*	
221b.	Lorica not flattened; cell with one flagellum	222
222a.	Lorica often opaque, generally dark brown to red; plastid green *Trachelomonas crebea*	
222b.	Lorica often transparent, colorless to light brown; plastid light brown *(Chrysococcus)*	223
223a.	Outer membrane (lorica) oval *Chrysococcus ovalis*	
223b.	Outer membrane (lorica) rounded	224
224a.	Lorica thickened around opening *Chrysococcus rubescens*	
224b.	Lorica not thickened around opening *Chrysococcus major*	
225a.	Plastids brown to red to olive- or blue-green	226
225b.	Plastids grass green	229
226a.	Plastid blue-green to blue *(Chroomonas)*	227
226b.	Plastids brown to red to olive-green *Rhodomonas lacustris*	
227a.	Cell not pointed at one end *Chroomonas setoniensis*	
227b.	Cell pointed at posterior end	228
228a.	Plastid one per cell *Chroomonas caudata*	
228b.	Plastids two per cell *Chroomonas nordstetii*	
229a.	Cell with colorless, rectangular wing *Pteromonas angulosa*	
229b.	No wing extending from cell	230
230a.	Cells with two chloroplasts, one on each side *Cryptoglena nigra*	
230b.	Cells with more than two chloroplasts	231
231a.	Cells flattened; margin rigid *(Phacus)*	232
231b.	Cell not flattened; margin rigid or flexible	233
232a.	Posterior spine short, bent *Phacus pleuronectes*	
232b.	Posterior spine long, straight *Phacus longicauda*	
233a.	Pyrenoid present in the single plastid; no paramylon; margin not flexible; two or more flagella per cell	234
233b.	Pyrenoid absent; paramylon present; several plastids per cell; margin flexible or rigid; one flagellum per cell	240
234a.	Cells long fusiform (tapering at each end) *(Chlorogonium)*	397
234b.	Cells not fusiform, generally almost spherical	235
235a.	Plastids numerous *Vacuolaria novo-munda*	
235b.	Plastids few, commonly one	236
236a.	Two flagella per cell	237
236b.	Four flagella per cell *Carteria multifilis*	
237a.	Cell with sheath of different shape from protoplast *Sphaerellopsis*	
237b.	Cell not as above *(Chlamydomonas)*	238
238a.	Distinct clear area across middle of cell *Chlamydomonas pertusa*	
238b.	No distinct clear area across middle of cell	239
239a.	Pyrenoid angular; eyspot in front third of cell *Chlamydomonas reinhardi*	
239b.	Pyrenoid circular; eyespot in middle third of cell *Chlamydomonas globosa*	
240a.	Cell flexible in form; paramylon a capsule or disc; cell elongate *(Euglena)*	241
240b.	Cell rigid in form; paramylon ring-shaped; cell almost spherical	250
241a.	Green plastids hidden by a red pigment *Euglena sanguinea*	
241b.	No red pigment except for the eyespot	242
242a.	Plastids at least one-fourth the length of the cell	243
242b.	Plastids discoid or at least shorter than one-fourth the length of the cell	244
243a.	Plastids two per cell *Euglena agilis*	
243b.	Plastids several per cell, often extending radiately from the center *Euglena viridis*	
244a.	Posterior end extending as a colorless spine	245
244b.	Posterior end rounded or at least with no colorless spine	247
245a.	Posterior end gradually narrowed to a spine *Euglena acus*	
245b.	Posterior end with an abrupt spine	246
246a.	Spiral markings very prominent and granular *Euglena spirogyra*	
246b.	Spiral markings fairly prominent, not granular *Euglena oxyuris*	

247a.	Small; length 35-55 microns	*Euglena gracilis*
247b.	Medium to large; length 65 microns or more	248
248a.	Medium in size; length 65-200 microns	249
248b.	Large in size; length 250-290 microns	*Euglena ehrenbergii*
249a.	Plastids with irregular edge; flagellum two times as long as cell	*Euglena polymorpha*
249b.	Plastids with smooth edge; flagellum about one-half as long as the cell	*Euglena deses*
250a.	Cell almost spherical or with abrupt posterior tip; paramylon ring-shaped	*(Lepocinclis)* 251
250b.	Posterior end of cell gradually pointed; cell margin with spiral ridges	*Phacus pyrum*
251a.	Posterior end with an abrupt, spine-like tip	*Lepocinclis ovum*
251b.	Posterior end rounded	*Lepocinclis texta*
252a.	Plastids brown	253
252b.	Plastids green	254
253a.	Cells in contact with one another	*Synura uvella*
253b.	Cells separated from one another by a space	*Uroglenopsis americana*
254a.	Colony flat; one cell thick	*Gonium pectorale*
254b.	Colony rounded; more than one cell thick	255
255a.	A long straight rod extending from each cell	*Chrysosphaerella longispina*
255b.	No long straight rod extending from each cell	256
256a.	Cells in contact with one another	257
256b.	Cells separated from one another by a space	260
257a.	Cells radially arranged	*Pandorina morum*
257b.	Cells all facing one direction	258
258a.	Cells each with two flagella	*(Pyrobotrys)* 259
258b.	Cells each with four flagella	*Spondylomorum quaternarium*
259a.	Eyespot in the wider (anterior) end of the cell	*Pyrobotrys stellata*
259b.	Eyespot in the narrower (posterior) end of the cell	*Pyrobotrys gracilis*
260a.	Cells more than 400 per colony	*Volvox aureus*
260b.	Cells less than 150 per colony	261
261a.	Cells of two distinct sizes in colony	*Pleodorina*
261b.	Cells all of one size in colony	*Eudorina elegans*

Green Algae and Associated Forms

262a.	Cells joined together to form a net	*Hydrodictyon reticulatum*
262b.	Cells not forming a net	263
263a.	Cells attached side by side to form a plate or ribbon one cell thick and one (or two) cells wide; Number of cells commonly 2, 4, or 8	*(Scenedesmus)* 264
263b.	Cells not attached side by side	268
264a.	Middle cells without spines but with pointed ends	265
264b.	Middle cells with rounded ends	266
265a.	All cells in colony erect	*Scenedesmus obliquus*
265b.	Median cells erect, terminal cells lunate	*Scenedesmus dimorphus*
266a.	Terminal cells with spines	267
266b.	Terminal cells without spines	*Scenedesmus bijuga*
267a.	Terminal cells with two spines each	*Scenedesmus quadricauda*
267b.	Terminal cells with three or more spines each	*Scenedesmus abundans*
268a.	Cells isolated or in nonfilamentous or nontubular thalli	269
268b.	Cells in filaments or other tubular or thread-like thalli	335
269a.	Cells isolated and narrowest at the center due to incomplete fissure	(desmids) 270
269b.	Cells isolated or in clusters but without central fissure	276
270a.	Each half of cell with three spine-like or pointed knobular extensions	*(Staurastrum)* 271
270b.	Cell margin with no such extensions	273
271a.	Margin of cell with long spikes	*Staurastrum paradoxum*
271b.	Margin of cell without long spikes	272
272a.	Ends of lobes with short spines	*Staurastrum polymorphum*
272b.	Ends of lobes without spines	*Staurastrum punctulatum*
273a.	Semi-cells with no median incision or depression	*(Cosmarium)* 274
273b.	Semi-cells with a median incision or depression	275
274a.	Median incision narrow linear	*Cosmarium botrytis*
274b.	Median incision wide, "U" shaped	*Cosmarium portianum*
275a.	Margin with rounded lobes	*Euastrum oblongum*
275b.	Margin with sharp-pointed teeth	*Micrasterias truncata*
276a.	Lunate or otherwise bent cells in a wide gelatinous matrix	*(Kirchneriella)* 277
276b.	Cells otherwise	278
277a.	Cells sharply pointed	*Kirchneriella lunaris*
277b.	Cells bluntly pointed	*Kirchneriella subsolitaria*
278a.	Cells elongate	279
278b.	Cells round to oval to angular	297
279a.	Cells quadrately arranged in fours	*Tetradesmus*
279b.	Cells not quadrately arranged	280

280a. Cells radiating from a central point .... *(Actinastrum)* 281

280b. Cells isolated or in irregular clusters 282

281a. Cells cylindric ....*Actinastrum gracillimum*

281b. Cells distinctly bulging .... *Actinastrum hantzschii*

282a. One or both cell ends gradually narrowed to an acute spine-like point .... *Ourococcus bicaudatus*

282b. Cells either with true spines or without spine-like points 283

283a. Cells with terminal spines 284

283b. Cells without terminal spines 285

284a. Cell ends blunt ...*Ophiocytium capitatum*

284b. Cell ends tapering ....*Schroederia setigera*

285a. Cells with colorless attachment area at one end .... *Characium*

285b. No attachment area at one end of cell.... 286

286a. Plastids two per cell; unpigmented area across center of cell .... *(Closterium)* 287

286b. Cell with plastid that continues longitudinally across the center of the cell 290

287a. Cell small; length up to 177 microns .... *Closterium acutum*

287b. Cell larger; length more than 240 microns 288

288a. Cell long and narrow; width up to 5 microns .... *Closterium aciculare*

288b. Cell wide; minimum width 19 microns.... 289

289a. Inner margin of cell straight .... *Closterium acerosum*

289b. Inner margin of cell tumid and curved ... . *Closterium moniliferum*

290a. Two, four, or many cells surrounded by homogenous envelope .... *Elakatothrix gelatinosa*

290b. No gelatinous envelope 291

291a. Cell five to ten times as long as broad 292

291b. Cell two to four times as long as broad ... 294

292a. Pyrenoid absent or one per cell .... *(Ankistrodesmus)* 293

292b. Pyrenoids several per cell .... *Closteriopsis brevicula*

293a. Cells bent ....*Ankistrodesmus falcatus*

293b. Cells straight .... *Ankistrodesmus falcatus* var. *acicularis*

294a. Plastid pale yellow-green; reddish oil droplets present .... *Pleurogaster*

294b. Plastid grass-green; storage food is starch 295

295a. Cells semi-circular; cell ends pointed but with no terminal spines .....*(Selenastrum)* 296

295b. Cells arcuate but less than semi-circular; cell ends pointed and each with a short spine ....*Closteridium lunula*

296a. Cells with rounded ends .... *Selenastrum capricornutum*

296b. Cells with pointed ends .... *Selenastrum gracile*

297a. Plastids green 298

297b. Plastids golden-brown; cells with pseudopodia 306

298a. Numerous gelatinous setae extending from surface of colony *Chaetopeltis megalocystis*

298b. No gelatinous setae extending from surface of colony 299

299a. Cells arranged in a flat regular colony 300

299b. Cells not in a tight, flat, regular colony ... 307

300a. Marginal cells with one or two or more spines or spine-like extensions 301

300b. Marginal cells otherwise 304

301a. Colonies limited to four cells with true spines .... *Tetrastrum*

301b. Colonies generally of eight or more cells, if limited to four cells, without true spines .... *(Pediastrum)* 302

302a. Numerous spaces between cells .... *Pediastrum duplex*

302b. Cells fitted tightly together 303

303a. Cell incisions deep and narrow .... *Pediastrum tetras*

303b. Cell incisions deep and wide .... *Pediastrum boryanum*

304a. All cells in contact with neighboring cells.. 305

304b. At least some cells lie free from one another .... *Dispora*

305a. Quadrangular space in center of each group of four cells .... *Crucigenia quadrata*

305b. No quadrangular space in center of each group of four cells .... *Prasiola nevadense*

306a. Cells isolated .... *Chrysamoeba*

306b. Cells in colonies .... *Chrysidiastrum*

307a. Plastid distinctly central .... *Apiococcus*

307b. Plastid parietal 308

308a. Cells angular 309

308b. Cells round to oval 311

309a. Two or more spines at each angle .... *Polyedriopsis spinulosa*

309b. Spines none or less than two at each angle .... *(Tetraedron)* 310

310a. Corners produced into processes .... *Tetraedron limneticum*

310b. Corners not produced into processes .... *Tetraedron muticum*

311a. Cells with long sharp spines 312

311b. Long sharp spines absent 315

312a. Cells round 313

312b. Cells oval 314

313a. Cells isolated .... *Golenkinia radiata*

313b. Cells in colonies ...*Micractinium pusillum*

314a. Each cell end with one spine .... *Diacanthos belenophoris*

314b. Each cell end with more than one spine ... . *Chodatella quadriseta*

315a. Each cell with a sheath which is not confluent with sheaths of adjacent cells .... *(Gloeocystis)* 316

315b. Cells or sheaths otherwise 317

316a. Colonies angular . . . *Gloeocystis planctonica*
316b. Colonies rounded . . . . . . *Gloeocystis gigas*
317a. Each cell group with two shapes of cells . . . . *Dimorphococcus lunatus*
317b. All cells of essentially the same shape . . . 318
318a. Colony of definite, regular form, round to oval 319
318b. Colony, if present, not a definite oval or sphere; or cells may be isolated 325
319a. Colony a tight sphere of cells 320
319b. Colony a loose sphere of cells enclosed by a membrane 321
320a. Sphere solid, slightly irregular; no connecting processes between cells . . . . *Planktosphaeria gelatinosa*
320b. Sphere hollow, regular; short connecting processes between cells . . . . *Coelastrum microporum*
321a. Cells round 323
321b. Cells oval . . . . *(Oocystis)* 322
322a. Cells with polar nodules . *Oocystis lacustris*
322b. Cells without polar nodules *Oocystis borgei*
323a. Cells connected to center of colony by branching stalk . . . . *(Dictyosphaerium)* 324
323b. No stalk connecting the cells . . . . *Sphaerocystis schroeteri*
324a. Cells rounded *Dictyosphaerium pulchellum*
324b. Cells straight, oval . . . . *Dictyosphaerium ehrenbergianum*
325a. Oval cells enclosed in a somewhat spherical, often orange-colored matrix . . . . *Botryococcus braunii*
325b. Cells round, isolated or in colorless matrix 326
326a. Adjoining cells with straight, flat walls between their protoplasts 327
326b. Adjoining cells with rounded walls between their protoplasts 328
327a. Cells embedded in a common gelatinous matrix . . . . *Palmella mucosa*
327b. No matrix or sheath outside of cell walls . . . . *Phytoconis botryoides*
328a. Cells loosely arranged in a large gelatinous matrix . . . . *Tetraspora gelatinosa*
328b. Cells isolated or tightly grouped in a small colony 329
329a. Cells located inside of protozoa . . . . *Zoochlorella*
329b. Cells not inside of protozoa 330
330a. Cells with two or more plastids . . . . *Palmellococcus*
330b. Each cell with a single plastid 331
331a. Plastid filling two-thirds or less of the cell . . 332
331b. Plastid filling three-fourths or more of the cell . . . . *Chlorococcum humicola*
332a. Cell diameter 2 microns or less; reproduction by cell division . . . . *Nannochloris*
332b. Cell diameter 2.5 microns or more; reproduction by internal spores . . . . . *(Chlorella)* 333
333a. Cells rounded 334
333b. Cells ellipsoidal to ovoid . . . . *Chlorella ellipsoidea*
334a. Cell 5-10 microns in diameter; pyrenoid indistinct . . . . *Chlorella vulgaris*
334b. Cell 3-5 microns in diameter; pyrenoid distinct . . . . *Chlorella pyrenoidosa*
335a. Cells attached end to end in an unbranched filament 336
335b. Thallus branched or more than one cell wide 362
336a. Plastids in form of one or more marginal, spiral ribbons; spirals may be incomplete . . 337
336b. Plastids not in form of spiral ribbons 342
337a. Spiral turn of plastic incomplete *Sirogonium*
337b. Plastid forming one or more spiral turns . . . . (Spirogyra) 338
338a. One plastid per cell 339
338b. Two or more plastids per cell 341
339a. Threads 18-26 microns wide . . . . *Spirogyra communis*
339b. Threads 28-50 microns wide 340
340a. Threads 28-40 microns wide . . . . *Spirogyra varians*
340b. Threads 40-50 microns wide . . . . *Spirogyra porticalis*
341a. Threads 30-45 microns wide; 3-4 plastids per cell . . . . *Spirogyra fluviatilis*
341b. Threads 50-80 microns wide; 5-8 plastids per cell . . . . *Spirogyra majuscula*
342a. Filaments when breaking, separating through middle of cells 343
342b. Filaments, when breaking, separating irregularly or at ends of cells 346
343a. Starch test positive; cell margin straight; one plastid, granular . . . . *(Microspora)* 344
343b. Starch test negative; cell margin slightly bulging; several plastids . . . . . *(Tribonema)* 345
344a. Cells 22-33 microns broad . . . . *Microspora amoena*
344b. Cells 11-20 microns broad . . . . *Microspora wittrockii*
345a. Plastids two to four per cell . . . . *Tribonema minus*
345b. Plastids more than four per cell . . . . *Tribonema bombycinum*
346a. Filaments short; generally 2-3 cells long . . . . *Stichococcus bacillaris*
346b. Filaments longer than 2-3 cells 347
347a. Marginal indentations between cells 348
347b. No marginal indentations between cells . . 349
348a. Cells much shorter than broad . . . . *Desmidium grevillii*
348b. Cells almost as long as broad . . . . *Hyalotheca mucosa*
349a. Plastids two per cell . . . . *(Zygnema)* 350

349b. Plastid one per cell (sometimes appearing numerous) 352

350a. Cell dense green, each plastid reaching to the wall .... *Zygnema sterile*

350b. Cells light green; plastids not completely filling the cell 351

351a. Width of thread 26-32 microns; maximum cell length 60 microns ... *Zygnema insigne*

351b. Width of thread 30-36 microns; maximum cell length 120 microns .... *Zygnema pectinatum*

352a. Some cells with walls having transverse wrinkles near one end; plastid an irregular net .... *(Oedogonium)* 353

352b. No apical wrinkles in wall; plastid not porous 356

353a. Thread diameter less than 25 microns 354

353b. Thread diameter 25 microns or more 355

354a. Thread diameter 9-14 microns .... *Oedogonium suecicum*

354b. Thread diameter 14-23 microns .... *Oedogonium boscii*

355a. Dwarf male plants attached to normal thread when reproducing .... *Oedogonium idioandrosporum*

355b. No dwarf male plants produced .... *Oedogonium grande*

356a. Plastid a flat or twisted axial ribbon .... *(Mougeotia)* 357

356b. Plastid an arcuate marginal band *(Ulothrix)* 359

357a. Threads with occasional "knee-joint" bends .... *Mougeotia genuflexa*

357b. Threads straight 358

358a. Threads 19-24 microns wide; pyrenoids 4-16 per cell .... *Mougeotia sphaerocarpa*

358b. Threads 20-34 microns wide; pyrenoids 4-10 per cell .... *Mougeotia scalaris*

359a. Threads 10 microns or less in diameter ... 360

359b. Threads more than 10 microns in diameter 361

360a. Threads 5-6 microns in diameter .... *Ulothrix variabilis*

360b. Threads 6-10 microns in diameter .... *Ulothrix tenerrima*

361a. Threads 11-17 microns in diameter .... *Ulothrix aequalis*

361b. Threads 20-60 microns in diameter .... *Ulothrix zonata*

362a. Thallus a tangled tubular mass of filaments .... *Thorea ramosissima*

362b. Thallus otherwise 363

363a. Thallus a gelatinous tube in which cells are embedded .... *Hydrurus*

363b. Thallus otherwise 364

364a. Thallus a flat plate of cells .... *Hildenbrandia rivularis*

364b. Thallus otherwise 365

365a. Thallus a tubular layer of cells .... *Enteromorpha intestinalis*

365b. Thallus otherwise 366

366a. Thallus a long tube without cross-walls ... 367

366b. Thallus otherwise 370

367a. Tube with constrictions especially at base of branches .... *Dichotomosiphon tuberosus*

367b. Tube with no constrictions ....*(Vaucheria)* 368

368a. Egg sac attached directly, without a stalk, to the main vegetative tube .... *Vaucheria sessilis*

368b. Egg sac attached to an abrupt, short, side branch 369

369a. One egg sac per branch .... *Vaucheria terrestris*

369b. Two or more egg sacs per branch .... *Vaucheria geminata*

370a. Thallus a leathery strand with regularly spaced swellings and a continuous membrane of cells 396

370b. Thallus otherwise 371

371a. Filament unbranched .... *Schizomeris leibleinii*

371b. Filament branched 372

372a. Branches in whorls (clusters) 373

372b. Branches single or in pairs 378

373a. Thallus embedded in gelatinous matrix .... *(Batrachospermum)* 374

373b. Thallus not embedded in gelatinous matrix 375

374a. Nodal masses of branches touching one another .... *Batrachospermum vagum*

374b. Nodal masses of branches separated from one another by a narrow space .... *Batrachospermum moniliforme*

375a. Main filament one cell thick ......*(Nitella)* 376

375b. Main filament three cells thick ....*(Chara)* 377

376a. Short branches on the main thread rebranched once .... *Nitella flexilis*

376b. Short branches on the main thread rebranched two to four times *Nitella gracilis*

377a. Short branches with 2 naked cells at the tip .... *Chara globularis*

377b. Short branches with 3-4 naked cells at the tip .... *Chara vulgaris*

378a. Most of filament surrounded by a layer of cells .... *Compsopogon coeruleus*

378b. Filament not surrounded by a layer of cells 379

379a. End cell of branches with a rounded or blunt-pointed tip 380

379b. End cell of branches with a sharp-pointed tip 387

380a. Plastid green; starch test positive 381

380b. Plastids red; starch test negative .... *Audouinella violacea*

381a. Some cells dense, swollen, dark green (spores); others light green, cylindric .... *Pithophora oedogonia*

381b. All cells essentially alike, being light to medium green, cylindric .... *(Cladophora)* 382

382a. Branches arising from below apices of cells ... *Cladophora profunda* var. *nordstedtiana*

382b. Branches arising from apices of cells 383

383a. Branches often appearing forked or in threes .... *Cladophora aegagropila*

383b. Branches distinctly lateral 384

384a. Branches forming acute angles with main thread, thus forming clusters .... *Cladophora glomerata*

384b. Branches forming wide angles with the main thread 385

385a. Threads crooked and bent .... *Cladophora fracta*

385b. Threads straight 386

386a. Branches few, seldom rebranching .... *Cladophora insignis*

386b. Branching numerous, often rebranching ... . *Cladophora crispata*

387a. Filaments embedded in gelatinous matrix . 388

387b. Filaments not embedded in gelatinous ... matrix 391

388a. Cells of main filament much wider than even the basal cells of the branches .... *(Draparnaldia)* 389

388b. No abrupt change in width of cells from main filament to branches ..*(Chaetophora)* 390

389a. Branches (from the main thread) with a central main axis ....*Draparnaldia plumosa*

389b. Branches diverging and with no central main axis .... *Draparnaldia glomerata*

390a. End cells long-pointed with colorless tips .... *Chaetophora attenuata*

390b. End cells abruptly pointed, mostly without long colorless tips ... *Chaetophora elegans*

391a. Branches very short, with no cross-walls .... *Rhizoclonium hieroglyphicum*

391b. Branches long, with cross-walls 392

392a. Branches ending in an abrupt spine having a bulbous base .... *(Bulbochaete)* 393

392b. Branches gradually reduced in width, ending in a long pointed cell, with or without color .... *(Stigeoclonium)* 394

393a. Vegetative cells 20-48 microns long .... *Bulbochaete mirabilis*

393b. Vegetative cells 48-88 microns long .... *Bulbochaete insignis*

394a. Branches frequently in pairs 395

394b. Branches mostly single .... *Stigeoclonium stagnatile*

395a. Cells in main thread 1-2 times as long as wide .... *Stigeoclonium lubricum*

395b. Cells in main thread 2-3 times as long as wide .... *Stigeoclonium tenue*

396a. Nodes covered by a ring of antheridial tissue .... *Lemanea annulata*

396b. Nodes covered by wart-like outgrowths of antheridial tissue .... *Sacheria*

397a. Pyrenoids two per cell .... *Chlorogonium elongatum*

397b. Pyrenoids several per cell .... *Chlorogonium euchlorum*

Bibliography

Adams, B. A. 1933. The role of actinomycetes in producing earthy tastes and smells in potable water. Rept. of Public Wks., Roads and Transport Congress. Paper No. 4. London, England.

Albertson, O. E. and R. J. Sherwood. 1969. Phosphate extraction process. Jour. Water Pollution Control Fed. 41: 1467-1490.

Allen, Mary B. 1955. General features of algal growth in sewage oxidation ponds. California State Water Pollution Control Board. Publ. No. 13. 48 p.

Aman, C. W. 1955. The relation of taste and odor to flavor. Taste and Odor Control Jour. 21 (No. 10): 1-4.

American Public Health Assn., Amer. Water Works Assn., Water Pollution Control Fed. 1971. Standard Methods for the Examination of Water and Wastewater. 13th ed. Amer. Pub. Hlth. Assn., New York, N.Y. 874 p.

American Water Works Association. 1925. Covers for reservoirs for filtered waters and ground waters. In Water Works Practice. William and Wilkins, Baltimore, Md. p. 243-245.

Archibald, R. E. M. 1972. Diversity in some South African diatom associations and its relation to water quality. Water Research 6:1229-1238.

Arnold, G. E. 1935. Weed growths in reservoirs and open canals. Jour. Amer. Water Wks. Assn. 27:1684-1693.

Ballantine, D. 1956. Two new species of *Gymnodinium* isolated from the Plymouth area. Jour. Marine Biol. Assn., United Kingdom 35:467-474.

Bartsch, A. F. 1954. Practical methods for control of algae and water weeds. Public Health Repts. 69:749-757.

Bartsch, A. F. (Chm.) 1961. Algae and Metropolitan Wastes. Trans. 1960 Seminar, Apr. 1960. U.S. Dept. Health, Educ., Welfare, Pub. Health Serv., Bur. State Services, Div. Water Supply and Pollution Control, Robt. A. Taft San. Engr. Center, Cincinnati, Ohio. SEC TR W61-3. 162 p.

Bartsch, A. F. (ed.) 1971. Algal assay procedure: Bottle test. National Eutrophication Research Program, Environmental Protection Agency. 82p.

Bauer, C. 1966. Taste and odor removal at Celina. Jour. Amer. Water Wks. Assn. 58:113-118.

Baylis, J. R. 1951. Fishy odor in water caused by Dinobryon. Pure Water. Dept. of Water and Sewers, Chicago, Ill. 3:128-150.

Baylis, J. R. 1955. Effect of microorganisms on lengths of filter runs. Water Wks. Eng. 108: 127-128, 158.

Baylis, J. R. 1957. Microorganisms that have caused trouble in the Chicago water system. Pure Water. Dept. of Water and Sewers, Chicago, Ill. 9:47-74.

Baylis, J. R. 1958. Microorganisms and short filter runs. Pure Water (Bur. of Water, Chicago, Ill.) 10:184-196.

Bick, H. 1963. A review of Central European methods for the biological estimation of water pollution levels. Bull. World Health Organization 29: 401-413.

Blum, J. L. 1956. The ecology of river algae. Bot. Rev. 22:291-341.

Blum, J. L. 1957. An ecological study of the algae of the Saline River, Mich. Hydrobiologia 9:361-408.

Blum, J. L. 1963. The influence of water currents on the life functions of algae. Ann. New York Acad. Sci. 108: 353-358.

Boschetti, M. M. 1957. A study in the chemical control of aquatic vegetation. Sanitalk 5 (No. 2):21-25.

Boucher, P. L. 1955. Micro-straining. Jour. Inst. Water Engrs. 9:561-595.

Boyer, C. S. 1927. Synopsis of North American Diatomaceae. Part II-Naviculatae, Surirellatae. Proc. Acad. Natural Sci. Philadelphia 79:229-583.

Braarud, T. 1945. A phytoplankton survey of the polluted waters of Inner Oslo Fjord. Hvalrodets Skrifter, Scientific Results of Marine Biological Research. No. 28:1-142.

Brinley, F. G. 1942. Biological studies, Ohio River pollution survey. I. Biological zones in a polluted stream. Sewage Wks. Jour. 14:147-159.

Brogan, R. H. 1961. Removal of sewage nutrients by algae. Pub. Health Repts. 76:301-308.

Brook, A. J. 1965. Planktonic algae as indicators of lake types, with special reference to the Desmidiaceae. Limnol. and Oceanog. 10:403-411.

Burlew, J. S. 1953. Algal culture from laboratory to pilot plant. Carnegie Inst. Washington Publ. 600. 357 p.

Butcher, R. W. 1949. Pollution and repurification as indicated by the algae. Fourth International Congress for Microbiology, held in 1947, Copenhagen, Denmark. Rept. of Proc. p. 449-450.

Cairns, Jr., J. 1956. Effects of increased temperatures on aquatic organisms. Indust. Wastes 1: 150-152.

Claassen, P. W. 1927. Biological studies of polluted areas in the Genesee River system. Part 3 in A biological survey of the Genesee River system. New York State Dept. Conservation. Suppl. to 16th Ann. Rept. for 1926.

California, 1952. California Water Quality Criteria. State of California.

Campbell, P. H. 1973. Studies in brackish water phytoplankton. Sea Grant Publ. UNC-SG-73-07. Univ. North Carolina. 409 p.

Clarke, K. B. 1961. Treatment difficulties due to a massive crop of *Ceratium hirundinella*. Jour. Inst. Water Eng. (Brit.) 15:233-238.

Clausen, H. T. 1959. Some observations on the action of algae on sewage in ponds. Jour. and Proc. Institute Sewage Purif. Part 3:345-348.

Cohen, S. G., and C. B. Reif. 1953. Cutaneous sensitization to blue-green algae. Jour. Allergy 24:452-457.

Cooke, W. B., and A. Hirsch. 1958. Continuous sampling of trickling filter populations. II. Populations. Sewage and Indust. Wastes 39: 138-156.

Cox, C. R. 1952. Water supply control. New York State Dept. Health. Bur. Environmental Sanitation. Bull. 22. 279 p.

Czernin-Chudinitz, C. W. 1955. Okologische Untersuchungen über des Phytoplankton des Klopeinersees in Kärnten. Arch. f. Hydrobiol. 51:54-97.

Daily, F. K. 1953. The Characeae of Indiana. Butler Univ. Bot. Stud. 11:5-49.

Damann, K. E. 1941. Quantitative study of the phytoplankton of Lake Michigan at Evanston, Illinois. Butler Univ. Bot. Stud. 5:27-44.

Davis, C. C. 1948. Studies of the effects of industrial pollution in the lower Patapsco River area. 2. The effect of copperas pollution on plankton. Chesapeake Biolog. Lab. Publ. No. 72. 12 p.

Davis, C. C. 1955. The Marine and Fresh-water Plankton. Michigan State Univ. Press, East Lansing, Mich. 562 p.

Davis, J. J. and R. F. Foster. 1958. Bioaccumulation of radioisotopes through aquatic food chains. Ecology 39:530-539.

Davis, J. J., R. W. Perkins, R. F. Palmer, W. C. Hanson, and J. F. Cline. 1958. Radioactive materials in aquatic and terrestrial organisms exposed to reactor effluent water. Second Internat. Conf. on Peaceful Uses of Atomic Energy. Paper No. 393.

Dawson, E. Y., A. A. Aleem, and B. W. Halstead. 1955. Marine algae from Palmyra Island with special reference to the feeding habits and toxicity of reef fishes. Allan Hancock Foundation Publ. Univ. Southern California, Occasional Paper No. 17. 39 p.

DeBard, W. W. and J. R. Baylis. 1946. Screen clogging by a rare species of algae. Water and Sewage Wks. 93:223-224.

Dempster, R. P. 1955. The use of copper sulfate as a cure for fish diseases caused by parasitic dinoflagellates of the genus *Oodinium*. Zoologica 40: 133-138.

Dillenberg, H. O. and M. K. Dehnel. 1960. Toxic waterbloom in Saskatchewan. 1959. Canadian Med. Assn. Jour. 83:1151-1154.

Drouet, F. 1956. A preliminary study of the algae of northwestern Minnesota. Proc. Minnesota Acad. Sci. 22: 116-138.

Drouet, F. 1963. Ecophenes of *Schizothrix calcicola* (Oscillatoriaceae). Proc. Acad. Nat. Sci. Philadelphia 115:261-281.

Drouet, F. 1968. Revision of the Classification of the Oscillatoriaceae. Acad. Nat. Sci. Philadelphia Monograph 15. 370 p.

Drouet, F. 1973. Revision of the Nostocaceae with Cylindrical Trichomes. Hafner Press, New York, N.Y. 292 p.

Drouet, F. and W. A. Daily. 1956. Revision of the coccoid Myxophyceae. Butler Univ. Bot. Stud. 12: 1-218.

Ehrlich, S. 1966. Two experiments in the biological clarification of stabilization-pond effluents. Hydrobiologia 27:70-80.

Ellis, J. B. and E. M. Sutherland. Stanley, A. O. and A. G. L. McNaughton (Chm.) 1951. Report of the International Joint Commission United States and Canada on the Pollution of Boundary Waters. Washington, D.C. and Ottawa, Canada. 312 p.

Eppley, R. W. and F. M. Maciase. 1962. Rapid growth of sewage lagoon *Chlamydomonas* with acetate. Physiologia Plantarum 15: 72-79.

Ewing, M. S. 1966. Algal community structure in artificial ponds subjected to continuous organic enrichment. Thesis, Oklahoma State Univ., Grad. Col. 41 p.

Feldman, J. 1951. Ecology of marine algae. Chapt. 16 in Manual of Phycology. G. M. Smith (ed.) Chronica Botanica Co., Wallham, Massachusetts. p. 313-334.

Filho, H. M. and D. M. M. Momoli. 1963. Diatomaceas no trato digestivo do Australorbis glabratus (Say, 1818). Botanica (Brazil), No. 9:1-7.

Fish, C. J. 1960. Limnological survey of Eastern and Central Lake Erie, 1928-1929. U.S. Dept. Interior, Fish and Wildlife Service, Special Scientific Rept. Fisheries No. 334.

Fitzgerald, G. P. and G. A. Rohlich. 1958. An evaluation of stabilization pond literature. Sewage and Indus. Wastes 30:1213-1224.

Fitzgerald, G. P. and F. Skoog. 1954. Control of blue-green algae blooms with 2,3-dichloronaphthoquinone. Sewage and Indus. Wastes 26:1136-1140.

Fjerdingstad, E. 1950. The microflora of the River Molleaa with special reference to the relation of the benthal algae to pollution. Folia Limnologica Scandinavica, No. 5. 123 p.

Fjerdingstad, E. 1964. Pollution of streams estimated by benthal phytomicro-organisms. I. A saprobic system based on communities of organisms and ecological factors. Int. Revue ges. Hydrobiol. 49:63-131.

Forest, H. W. 1954 Handbook of Algae with Special Reference to Tennessee and the Southeastern United States. Univ. Tennessee Press, Knoxville, Tenn. 467 p.

Fritsch, F. E. 1935, 1945. The Structure and Reproduction of the Algae. Cambridge Univ. Press, England. Vol. 1:791 p. Vol. 2:939 p.

Frost, V. M. and W. F. Rippe. 1929. Experiences in chlorinating condenser circulating water. Wallace and Tiernan Tech. Publ. No. 112. 32 p.

Gainey, P. L. and T. H. Lord. 1952. Microbiology of Water and Sewage. Prentice-Hall, New York. 430 p.

Gerloff, G. C., G. P. Fitzgerald, and F. Skoog. 1950. The mineral nutrition of *Coccochloris peniocystis*. Amer. Jour. Bot. 37:835-840.

Glenn, L., H. Bishop, and C. E. Dunbar. 1960. Algal parasite in fish. Prog. Fish Culturist 22:120.

Gojdics, M. 1953. The genus *Euglena*. Univ. Wisconsin Press, Madison, Wis. 268 p.

Gotaas, H. B., W. J. Oswald, and H. F. Ludwig. 1954. Photosynthetic reclamation of organic wastes. Sci. Monthly 79:368-379.

Graham, D. W. 1942. Investigation of an unusual natural water softening. Jour. Amer. Water Wks. Assn. 34:589-594.

Habekost, R. C., I. M. Fraser, and B. W. Halstead. 1955. Observations on toxic marine algae. Jour. Washington State Acad. Sci. 45:101-103.

Hale, F. E. 1950. The use of copper sulphate in control of microscopic organisms. Phelps Dodge Refining Corp., New York. 44 p.

Happy, Jr., A. W. 1961. Waste Stabilization Lagoons. Proc. Symposium at Kansas City, Missouri, August 1960. U.S. Dept. Health, Educ., Welfare, Pub. Health Serv. Div. of Water Supply and Pollution Control, Washington, D.C. Pub. Health Service Publ. No. 872. 170 p.

Harrington, G. E. 1935. Interesting experiences with microorganisms in the Washington water supply. Proc. 9th Ann. Conf., Maryland-Delaware Water and Sewerage Assn. p. 74-99.

Hart, W. B. 1956. Specialized biological treatment opens new possibilities in treatment of industrial wastes. Indust. and Eng. Chem. 48:93A-95A.

Heise, H. A. 1951. Symptoms of hay fever caused by algae. II. *Microcystis,* another form of algae producing allergenic reactions. Ann. Allergy 9:100-101.

Hemens, J. and G. J. Stander. 1968. Nutrient removal from sewage effluents by algal activity. Fourth International Conference on Water Pollution Research, Prague, Sept. 1968. Pergamon Press. 11 p.

Henderson, C. 1949. Manganese for increased production of water-bloom algae in ponds. Progressive Fish-Culturist 11:157-159.

Hobbs, A. T. 1954. The biological examination of water. Chapt. 18 in Manual of British water supply practice. Ed. 2. H. Heffer and Sons, Cambridge, England. p. 716-758.

Horasawa, I. 1942. A preliminary report on the biological index of water pollution. Zool. Mag. (Tokyo) 54:37-38.

Horning II, W. B., R. Porges, H. F. Clarke, and W. B. Cooke. 1964. Waste stabilization pond study, Lebanon, Ohio. Pub. Hlth. Serv. Publ. No. 999-WP-16:1-48.

Howard, N. J., and A. E. Berry. 1933. Algal nuisances in surface waters. Canadian Jour. Public Health 24:377-384.

Huber-Pestalozzi, G. 1938-1955. Das Phytoplankton des Süsswassters. In A. Thienemann, Die Binnengewässer, Band 16, Teil 1-4. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, Germany.

Huff, N. L. and G. O. House. 1916. Copper sulfate treatment of St. Paul, Minnesota water supply. Jour. Amer. Water Wks. Assn. 3:581-621.

Hull, C. H. J. 1961. Algae and organic waste assimilation in tidal estuaries. Proc. 34th Ann. Conf., Maryland-Delaware Water and Sewage Assn. :37-52.

Hustedt, F. 1930. Bacillariophyta (Diatomeae). Heft 10 in A. Pascher, Die Süsswasser-Flora Mitteleuropas. Gustav Fisher, Jena, Germany. 466 p.

Ingram, W. M. and C. M. Palmer. 1952. Simplified procedures for collecting, examining, and recording plankton in water. Jour. Amer. Water Wks. Assn. 44: 617-624.

Ingram, W. M., and G. W. Prescott. 1954. Toxic fresh-water algae. Amer. Midland Naturalist 52:75-87.

Isokawa, S. 1956. An alga growing on the teeth and their surrounding tissues of fish. Zool. Mag., Japan. 65:319-321.

Jaag, O. 1955. The Alpine lakes, a heritage in danger. World Health Org. News Letter 8(5):3.

Jackson, D.F. (ed.) 1964. Algae and Man. Proc. NATO Advanced Study Institute, July-Aug. 1962, Louisville, Kentucky. Plenum Press, New York, 434 p.

Jackson, D. F. 1964. The effects of algae on water quality. Proc. First Ann. Water Qual. Res. Symposium, N.Y. State Dept. Health and N.Y. Water Pollution Assn., Albany, N.Y. p. 2-23.

Jackson, D. F. (ed.) 1968. Algae, Man and the Environment, Proc. International Symposium, June 1967, Syracuse, New York. Syracuse Univ. Press, Syracuse, New York. 554 p.

Jahn, F. L. 1949. How to Know the Protozoa. Wm. C. Brown Co., Dubuque, Iowa. 234 p.

Johnson, L. D. 1955. Control of *Ulothrix zonata* in circular ponds. Prog. Fish Culturist 17(3):126-128.

Jones, M. H. 1937. Algae in some thermal and mineral waters of Colorado. Univ. Colorado Stud. 24:117-119.

Jorgensen, E. G. 1952. Notes on the ecology of the diatom *Navicula accomoda* Hustedt. Saertryk of Botanisk Tidsskrift 49(1):189-191.

Jurgens, K. C. 1953. Red tide of Lake Austin. Texas Game and Fish 11(11):8,24.

Kawakita, S. 1955-1956. The easy classification of important microorganisms in Japanese water supplies. (In Japanese.) Jour. Japanese Water Wks. and Sewerage Assn., Nos. 251, 253, 257, 258, 263, 265.

Kehr, R. W., W. C. Purdy, J. B. Lackey, O. R. Placak, and W. E. Burns. 1941. A study of pollution and natural purification of the Scioto River. U.S. Public Health Service, Public Health Bull. No. 276. 153 p.

Kennedy, A. S. 1948. The algal environment in relation to fish. Jour. New England Water Wks. Assn. 62:196-201.

Ketchum, B. H. 1950. Hydrographic factors involved in the dispersion of pollutants introduced into tidal waters. Jour. Boston Soc. Civil Engineer 37:296-314.

Kofoid, C. A. 1923. Microscopic organisms in reservoirs. Jour. Amer. Water Wks. Assn. 40:183-191.

Kolkwitz, R. 1950. Oekologie der Saprobien. Uber die Bezeihungen der Wasserorganismen zur Umwelt. Schriftenreihe des Vereins für Wasser-, Boden-, und Lufthygiene, No. 4. 64 p.

Krauss, R. W. 1956. Photosynthesis in the algae. Indust. and Eng. Chem. 48:1449-1455.

Krauss, R. W. 1962. Mass culture of algae for food and other organic compounds. Amer. Jour. Bot. 49:425-435.

Kuran, O. G. and H. H. Angell. 1953. Rout reservoir algae. Amer. City 68 (No. 10):90-91.

Lackey, J. B. 1938. The manipulation and counting of river plankton and changes in some organisms due to formalin preservation. Public Health Repts. 53:2080-2093.

Lackey, J. B. 1939. Aquatic life in waters polluted by acid mine waste. Public Health Repts. 54:740-746.

Lackey, J. B. 1941. Two groups of flagellated algae serving as indicators of clean water. Jour. Amer. Wks. Assn. 33:1099-1110.

Lackey, J. B. 1942a. Plankton ecology of the Licking River, Ky. U.S. Public Health Service, San. Eng. Div., Water and Sanitation Investig., Cincinnati, Ohio 14 p. (Mimeographed.)

Lackey, J. B. 1942b. The effects of distillery wastes and waters on the microscopic flora and fauna of a small creek. Public Health Repts. 57:253-260.

Lackey, J. B. 1944. Quality and quantity of plankton in the south end of Lake Michigan in 1942. Jour. Amer. Water Wks. Assn. 36:669-674.

Lackey, J. B. 1948. The use of biological indicators in determination of stream pollution. Univ. Michigan School Public Health. Lectures presented at Inservice Training Course in Sewage and Industrial Waste Disposal. p. 109-118. (Mimeographed.)

Lackey, J. B. 1956. Stream enrichment and microbiota. Public Health Repts. 71:708-718.

Lackey, J. B. and E. R. Hupp. 1956. Plankton populations in Indiana's White River. Jour. Amer. Water Wks. Assn. 48:1024-1036.

Lackey, J. B. and J. A. Hynes. 1955. The Florida Gulf Coast red tide. Florida Eng. and Indust. Exp. Sta. Bull., Series No. 70. 23 p.

Laughlin, H. F. 1954. Palatable level with the threshold odor test. Taste and Odor Control Jour. 20 (No. 8):1-4.

Lauter, C. J. 1937. The significance of microorganisms in plant design. Proc. 11th Ann. Conf. Maryland-Delaware Water and Sewerage Assn. p. 67-74.

Lawrence, J. M. 1954. Control of a branched alga *Pithophora,* in farm fish ponds. Progressive Fish Culturist, 16:83-87.

Leibee, H. C., and R. L. Smith. 1953. Control of algae, a means of prolonging the life of lakes. Wastes Eng. 24: 620-621.

Lendall, H. N. 1946. Comprehensive survey of taste and odor problems. Water Wks. Eng. 99: 1237-1238.

Liebmann, H. 1951. Handbuch der Frischwasser-, und Abwasserbiologie. Band 1. R. Oldenbourg, München, Germany. 539 p.

Lund, J. W. C. 1954. The importance of algae to waterworks engineers. Jour. Inst. Water Engrs. 8:497-504.

MacKenthun, K. M. and C. D. McNabb. 1961. Stabilization pond studies in Wisconsin, Jour. Water Pollution Control Fed. 33:1234-1251.

MacKenthun, K. M. 1969. The Practice of Water Pollution Biology. U.S. Dept. Interior, Fed. Water Pollution Control Admin., Div. of Tech. Support. 281 p.

Maloney, T. E., and C. M. Palmer. 1956. Toxicity of six chemical compounds to thirty cultures of algae. Water and Sewage Wks. 103:509-513.

Maloney, T. E. 1958. Control of algae with chlorophenyl dimethyl urea. Jour. Amer. Water Wks. Assn. 50:417-422.

Maloney, T. E. 1958. Identification of odor producing substances elaborated by algae. Pub. Works Mag. 89:99-100.

Maloney, T. E. 1966. Detergent phosphorus effect on algae. Jour. Water Pollution Control Fed. 38:38-45.

Maloney, T. E., H. F. Ludwig, J. A. Harmon, and L. McClintock. 1960. Effect of whey wastes on stabilization ponds. Jour. Water Pollution Control Fed. 32:1283-1299.

Marx, A. J. 1951. Pre-treatment basin for algae removal. Taste and Odor Control Jour. 17 (No. 6):1-8.

Matheson, D. H. 1952. The effects of algae in water supplies. International Water Supply Assn., Gen. Rept. to 2d Congress, Paris, France. 82 p.

Matheson, D. H. and A. V. Forde. 1957. Survey of water purification practice in Canada. Jour. Amer. Water Wks. Assn. 49:1522-1530.

McCarry, C. 1973. Yesterday lingers along the Connecticut. National Geographic 142:334-368.

McCauley, R. N. 1966. The biological effects of oil pollution in a river. Limnol. Oceanog. 11:475-486.

McFarren, E. F., M. L. Schafer, J. E. Campbell, K. H. Lewis, E. T. Jensen, and E. J. Schantz. 1956. Public health significance of paralytic shellfish poison: a review of literature and unpublished research. Proc. National Shellfisheries Assn. 47:114-141.

Merz, R. C., R. G. Zehnpfennig, and J. R. Klima. 1962. Chromatographic assay of intracellular products of algal metabolism. Jour. Water Pollution Control Fed. 34:103-115.

Middleton, F. M., G. Wallace, and A. A. Rosen. 1956. Drinking water taste and odor, correlation with organic chemical content. Indust. Eng. Chem. 48:268-274.

Mifune, N., H. Hirose, and K. Tsumura. The thermal algae in a certain strong radioactive spring in Japan. Hot Springs Science (Ansen Kagaku) Vol. 10. No. 3.

Mills, D. A. 1961. Depth and loading rates of oxidation ponds. Water and Sewage Wks. 108:343-346.

Milner, H. W. 1955. Some problems in large-scale culture of algae. Sci. Monthly 80:15-20.

Minnesota Department of Health. 1941. Numerical rating of water supplies. Section 14, Table 1416, in Manual of Water Supply Sanitation. Minneapolis, Minn.

Moore, G. T. and K. F. Kellerman. 1904. A method of destroying or preventing the growth of algae and certain pathogenic bacteria in water supplies. U.S. Dept. Agriculture, Bur. Plant Indus., Bull. No. 64. 44 p.

Mrva, A. F. 1965. Operation of the South District filtration plant. Pure water, Chicago Bur. Waters 17:51-71.

Mt. Pleasant, R. C., M. C. Rand, and N. L. Nemerow. 1961. Chemical and microbiological aspects of Oneida Lake. N.Y. State Dept. of Health, Research Rept. No. 8.

Muckle, R. 1956. The limnological conditions for a large water-supply intake on the Uberlinger Lake (Lake Constance). Gas-u Wasserfach 97:213-222.

Muncy, R. J. 1963. Observations on the factors involved with fish mortality as the result of dinoflaggellate bloom in a freshwater lake. Proc. 17th Ann. Conf. Southeastern Assn. Game and Fish Comm. p. 218.

Myers, H. C. 1947. The role of algae in corrosion. Jour. Amer. Water Wks. Assn. 39:322-324.

Myers, J. 1948. Studies of sewage lagoons. Pub. Wks. 97 (12):25-27.

National Institute for Water Research. 1963. Guide to operations of raw sewage stabilization ponds. Council for Scientific and Indus. Research. Rept. of director for 1962. YCSIR Special Rept. No. WAT.27:1-76. Pretoria, South Africa.

National Water Quality Network. 1958-1963. Annual Compilation of Data. Pub. Health Serv. Publ. No. 663. Editions: 1958, plus Supplement 1; 1959; 1960, plus Supplement 2; 1961; 1962; 1963 (Water Pollution Surveillance System).

Needham, J. G. and J. T. Lloyd. 1928. The Life of Inland Waters. Amer. Viewpoint Soc., N. Y. p. 77-88.

Neel, J. K. 1953. Certain limnological features of a polluted irrigation stream. Trans. Amer. Microscop. Soc. 72-119-135.

Neel, J. K., J. H. McDermott, and C. A. Monday, Jr. 1961. Experimental lagooning of raw sewage at Fayette, Missouri. Jour. Water Pollution Control Fed. 33:603-641.

Nelson, T. C. 1941. Discussion of article by W. D. Monie on algae control. Jour. Amer. Water Wks. Assn. 33:716-720.

Nesin, B. C. and R. L. Derby. 1954. Methods of controlling aquatic growths in reservoirs. Jour. Amer. Water Wks. Assn. 46:1141-1158.

Nigrelli, R. F., J. J. A. McLauchlin and S. Jakowsku. 1958. Histozoic algal growth in fish. Copeia No. 4:331-333.

Nygaard, G. 1945. Dansk Planteplankton. Gyldendalske Boghandel Nordisk Forlag, Copenhagen, Denmark. 52 p.

Oborn, E. T., and E. C. Higginson. 1954. Biological corrosion of concrete. Joint Rept. Field Crops Res. Branch, Agric. Res. Service, U. S. Dept. Agric., and Bur. Reclamation, U.S. Dept. Interior. 8 p.

Ontario Water Resources Commission. 1959. *Cladophora* investigations, 1959. A report of observations on the nature and control of excessive growth of *Cladophora* sp. in Lake Ontario. Ontario Water Resources Commission. 30 p.

Oswald, W. J., H. B. Gotaas, C. G. Golueke and W. R. Kellen. 1957. Algae in waste treatment. Sewage and Indus. Wastes 29:437-457.

Palmer, C. M. 1931. Algae of Marion County, Indiana. A description of thirty-two forms. Butler Univ. Bot. Stud. 2:1-21.

Palmer, C. M. 1942. Additional records for algae, including some of the less common forms. Butler Univ. Bot. Stud. 5:224-234.

Palmer, C. M. 1956. Evaluation of new algicides for water supply purposes. Jour. Amer. Water Wks. Assn. 48:1133-1137.

Palmer, C. M. 1958a. Algae and other interference organisms in New England water supplies. Jour. New England Water Wks. Assn. 72:27-46.

Palmer, C. M. 1958b. Algae and other organisms in waters of the Chesapeake area. Jour. Amer. Water Wks. Assn. 50:938-950.

Palmer, C. M. 1959. Algae in Water Supplies. An Illustrated Manual on the Identification, Significance, and Control of Algae in Water Supplies. U. S. Dept. Health, Educ., Welf., Pub. Health Serv., Bur. State Services, Div. Water Pollution Control, Robt. A. Taft San. Engr. Center, Cincinnati, Ohio. Pub. Health Serv. Publ. No. 657. 88 p.

Palmer, C. M. 1960. Algae and other interference organisms in waters of the South Central United States. Jour. Amer. Water Wks. Assn. 52:897-914.

Palmer, C. M. 1961. Algae and other interference organisms in water supplies of California. Jour. Amer. Water Wks. Assn. 53:1297-1312.

Palmer, C. M. 1962. Algae in water supplies of Ohio. Ohio Jour. Sci. 62:225-244.

Palmer, C. M. 1967a. Algae and associated organisms in West Virginia waters; problems and control measures. Castanea 32:123-133.

Palmer, C. M. 1967b. Algae in relation to water quality in Pennsylvania. Proc. Pennsylvania Acad. Sci. 51:74-85.

Palmer, C. M. 1967c. Biological aspects of water supply and treatment in Virginia with particular reference to algae. Virginia Jour. Sci. 18 (New Series No.1):6-12.

Palmer, C. M. 1967d. Environmental needs of nuisance organisms. Proc. 4th Ann. Water Quality Res. Symposium, N.Y. State Dept. Health, Albany, N.Y. p. 8-35.

Palmer, C. M. 1967e. Nutrient assimilation by algae in waste stabilization ponds. Proc. Indiana Acad. Sci. for 1966. 76:204-209.

Palmer, C. M. 1969a. A composite rating of algae tolerating organic pollution. Jour. Phycology 5:78-82.

Palmer, C. M. 1969b. Algal records for three Indiana sewage stabilization ponds. Proc. Indiana Acad. Sci. for 1968. 78:139-145.

Palmer, C. M. 1975. Algae in American sewage stabilization ponds. Revista de Microbiologia (Sao Paulo, Brazil) 5(4):75-80, 1974 (Released Aug. 1975).

Palmer, C. M. and H. H. Black. 1955. Plankton removal tests and potable water supply at Naval Station, Argentina, Newfoundland. Dept. Health, Ed. and Welfare, Public Health Service, Robt. A. Taft San. Eng. Center, Cincinnati, Ohio. 60 p. (Mimeographed.)

Palmer, C. M. and W. M. Ingram. 1955. Suggested classification of algae and protozoa in sanitary science. Sewage and Indust. Wastes 27:1183-1188.

Palmer, C. M. and T. E. Maloney. 1953. The use of algal cultures in experiments concerned with water supply problems. Butler Univ. Bot. Stud. 11:87-90.

Palmer, C. M. and T. E. Maloney. 1954. A new counting slide for nannoplankton. Amer. Soc. Limnol. and Oceanog., Special Publ. No. 21. 6 p.

Palmer, C. M. and H. W. Poston. 1956. Algae and other interference organisms in Indiana water supplies. Jour. Amer. Water Wks. Assn. 48:1335-1346.

Palmer, C. M. and C. M. Tarzwell. 1955. Algae of importance in water supplies. Public Wks. Mag. 86 (No. 6):107-120.

Palmer, C. M. and H. J. Walter. 1954. Algae of importance in water supplies. Plans for a manual with keys and color plates. News. Bull., Phycological Soc. Amer. 7 (No. 21): 6-7.

Parker, B. C. and R. M. Brown, Jr. 1971. Contributions in Phycology. Allen Press, Inc. Lawrence, Kansas. 196 p.

Parker, C. D. 1966. Food cannery waste treatment by lagoons and ditches at Shepparton, Victoria, Australia. Proc. 91st Indus. Waste Conf. May 1966. Pt. 1. Engr. Bull. Purdue Union. 50 (No. 1). Engr. Extension Ser. No. 121:284-301.

Parker, C. D., H. L. Jones, and N. C. Green. 1959. Performances of large sewage lagoons at Melbourne, Australia. Sewage and Indus. Wastes. 31:133-152.

Patrick, R. 1939. Nomenclature changes in two genera of diatoms. Notulae Naturae, Acad. Natural Sci. Philadelphia. No. 28. 11 p.

Patrick, R. 1943. The diatoms of Linsley Pond. Proc. Acad. Natural Sci. Philadelphia. 95:53-110.

Patrick, R. 1948. Factors effecting the distribution of diatoms. Bot. Rev. 14:473-524.

Patrick, R. 1950. A proposed biological measure of stream conditions. Proc. 5th Indust. Waste Conf., Purdue Univ. Eng. Bull. 34:379-399.

Patrick, R. 1961. A study of the number and kinds of species found in rivers in eastern United States. Proc. Acad. Natural Sci. of Philadelphia 113:215-258.

Patrick, R. 1955. Diatoms as an indication of river change. Proc. 9th Indus. Waste Conf. 1954. Purdue Univ. Engr. Bull. 39:325-330.

Patrick, R., N. H. Hohn, and J. H. Wallace. 1954. A new method for determining the pattern of the diatom flora. Notulae Naturae, Acad. Natural Sci. Philadelphia. No. 259. 12 p.

Patrick, R. and C. Reimer. 1966. The Diatoms of the United States. Acad. Natural Sci. Philadelphia. Monograph No. 13:39-44.

Pearsall, W. H., A. C. Gardiner, and F. Greenshields. 1946. Freshwater biology and water supply in Britain. Freshwater Biolog. Assn. of the British Empire, Scientific Publ. No. 11. 90 p.

Platt, E. L. 1915. The population of the blanket-algae of fresh-water ponds. Amer. Naturalist 49:752-762.

Prescott, G. W. 1938. Objectionable algae and their control in lakes and reservoirs. Louisiana Municipal Rev., Vol. 1, Nos. 2 and 3. 10 p.

Prescott, G. W. 1939. Some relationships of phytoplankton to limnology and aquatic biology. In F. R. Moulton, ed., Problems of lake biology. Amer. Assn. Advancement Sci., Science Press, Lancaster, Pa. p. 65-78.

Prescott, G. W. 1951a. Algae of the western Great Lakes area, exclusive of desmids and diatoms. Cranbrook Inst. Sci., Bloomfield Hills, Mich. Bull No. 31. 946 p.

Prescott, G. W. 1951b. Lake types and algal distribution. In Algae of the western Great Lakes area. Cranbrook Inst. Sci., Bloomfield Hills, Mich. Bull No. 31. p. 13-33.

Prescott, G. W. 1968. The Algae: A Review. Houghton, Mifflin Co. 436 p.

Porges, R. and K. M. MacKenthun. 1963. Waste stabilization ponds, use, function, and biota. U.S. Dept. Health, Educ., Welf., Robt. A. Taft San. Engr. Center, Cincinnati, Ohio. 40 p. (Mimeographed.)

Potash, M. 1956. A biological test for determining the potential productivity of water. Ecology 37:631-639.

Rafter, G. W. 1900. The microscopical examination of potable water. Ed. 2. Van Nostrand Co., New York. 160 p.

Rohlich, G. A. (Chm.) 1969. Eutrophication Causes, Correctives. Proc. Symposium 1967. National Acad. Sci., Washington. 661 p.

Romano, A. H. 1958. Identification of odors produced by actinomycetes. Pub. Works Mag. 89:100-101.

Romano, A. H. and R. S. Safferman. 1963. Studies on actinomycetes and their odors. Jour. Amer. Water Wks. Assn. 55:169-176.

Rosowski, J. R. and B. C. Parker. 1971. Selected Papers in Phycology. Dept. Botany, Univ. Nebraska, Lincoln, Nebraska. 876 p.

Rondhovde, I. N. et al. 1953. Removal of tastes and odors. Proc. 35th Ann. Texas Water and Sewage Wks. Short School. p. 98.

Round, R. D. 1965. The Biology of the Algae. Edw. Arnold, Ltd., London, England. 269 p.

Ruttner, F. 1953. Fundamentals of Limnology. Univ. Toronto Press. 242 p.

Safferman, R. S. and M. E. Morris. 1962. A method for the isolation and enumeration of actinomycetes related to water supplies. Robt. A. Taft San. Engr. Center, Tech. Rept. W62-10. 15 p.

Schlichting, Jr., H. E. and R. A. Gearheart. 1966. Some effects of sewage effluent upon phyco-periphyton in Lake Murray, Oklahoma. Proc. Oklahoma Acad. Sci. 46:19-24.

Schlichting, Jr., H. E. 1971. Protein quality of some freshwater algae. Econ. Bot. 25:317-319.

Schroeder, H. 1939. Die Algenflora der Mulde. Ein Beitrag zur Biologie saprober Flüsse. Pflanzenforschung. 21:1-88.

Schwimmer, M., and D. Schwimmer. 1955. The role of algae and plankton in medicine. Grune and Stratton, New York. 85 p.

Shilo, M. and M. Shilo. 1953. Conditions which determine the efficiency of ammonium sulfate in the control of *Prymnesium parvum* in fish breeding ponds. Appl. Microbiol. 1:330-333.

Sigworth, E. A. 1957. Control of odor and taste in water supplies. Jour. Amer. Water Wks. Assn. 49:1507-1521.

Silva, P. C., and G. F. Papenfuss. 1953. A systematic study of the algae of sewage oxidation ponds. California State Water Pollution Control Board, Publ. No. 7. 34 p.

Silvey, J. K., and A. W. Roach. 1956. Actinomycetes may cause tastes and odors in water supplies. Public Wks. Mag. 87:103-106, 210, 212.

Sladecek, V. 1966. Water quality system. Verh. Internat. Verein. Limnol. 16:809-816.

Smith, G. M. 1924. Ecology of the plankton algae in the Palisades Interstate Park, including the relation of control methods to fish culture. Roosevelt Wildlife Bull. 2(2):93-195.

Smith, G. M. 1950. The fresh-water algae of the United States. Ed. 2. McGraw-Hill, New York. 719 p.

Smith, G. M. (ed.) 1951. Manual of Phycology. Cronica Botanica Co., Massachusetts. 375 p.

Snow, E. A. and A. Iantosca. 1952. Treating algae under the ice at Westfield, Mass. Jour. New England Water Wks. Assn. 66:47-54.

Snow, Jr., E. A. 1958. The most troublesome algae in New England waters. Jour. New England Water Wks. Assn. 72:328-331.

Sommer, H. and K. F. Meyer. 1948. Mussel poisoning—a summary. In Manual for control of communicable diseases in California. California State Dept. Public Health.

Southgate, B. A. 1948. Treatment and disposal of industrial waste waters. British Govt. Dept. Scientific and Indust. Res., London, England.

Spencer, R. R. 1930. Unusually mild recurring epidemic simulating food infection. Public Health Repts. 45:2867-2877.

Starbird, E. 1972. A river restored: Oregon's Willamette. National Geographic 141:817-835.

Stein, J. R. (ed.) 1973. Handbook of Phycological Methods, Culture Methods and Growth Measurements. Cambridge Univ. Press, London, England. 448 p.

Stein, J. R. and C. C. Amundsen. 1967. Studies on snow algae and fungi from the Front Range of Colorado. Canadian Jour. Bot. 45:2033-2045.

Stevens, W. K. 1974. Great Lakes pollution fight is gaining. The New York Times, May 23. p. 1, 42.

Stewart, A. G., D. A. Barnum, and J. A. Henderson. 1950. Algal poisoning in Ontario. Canadian Jour. Comparative Med. 14:197-202.

Sundene, O. 1953. The algal vegetation of Oslo Fjord. Skr. Norsk. Vidensk. Akad., Norway, No. 2. 244 p.

Swartz, S. O. 1955. Review of microorganisms in water supplies. Jour. New England Water Wks. Assn. 69:217-227.

Symons, G. E. 1956. Tastes and odor control. Water and Sewage Wks. 103:307-310, 348-355.

Taft, C. E. 1965. Water and Algae—World Problems. Educational Publishers, Inc., Chicago, Ill. 236 p.

Tarlton, E. A. 1949. Algae control at Danbury, Conn. Jour. New England Water Wks. Assn. 63:165-174.

Tarzwell, C. M. and C. M. Palmer. 1951. Ecology of significant organisms in surface water supplies. Jour. Amer. Water Wks. Assn. 43:568-578.

Tarzwell, C. M. (ed.) 1957. Biological Problems in Water Pollution Trans. (First) Seminar. Robt. A. Taft San. Engr. Center, Cincinnati, Ohio, Apr. 1956. U. S. Dept. Health, Educ., Welfare, Pub. Health Serv., Bur. State Services, Div. San. Engr. Services. Robt. A. Taft San. Engr. Center. 272 p.

Tarzwell, C. M. (ed.) 1960. Biological Problems in Water Pollution. Trans. Second Seminar. U. S. Dept. Health, Educ., Welfare, Pub. Health Serv., Bur. State Services, Div. Water Supply and Pollution Control, Robt. A. Taft San. Engr. Center, Cincinnati, Ohio. 285 p.

Tarzwell, C. M. (ed.) 1965. Biological Problems in Water Pollution. Third Seminar. Aug. 1962. Research Branch, Robt. A. Taft San. Engr. Center. U.S. Dept. Health, Educ., Welfare, Pub. Health Serv., Div. Water Supply and Pollution Control, Cincinnati, Ohio. Pub. Health Serv. Publ. No. 999-WP-25. 424 p.

Taylor, E. W. 1955. The reservoirs of the Metropolitan Water Board and their influence upon the character of the stored water. Proc. International Assn. Theoretical and Appl. Limnol. 12:48-65.

Tiffany, L. S. 1928. Some economic aspects of the algae. School Sci. and Math. 28:583-593.

Tiffany, L. S. 1938. Algae, the Grass of Many Waters. C. C. Thomas, Publisher. Springfield, Ill. 171 p.

Tiffany, L. H. and M. E. Britton. 1952. The algae of Illinois. Univ. Chicago Press, Chicago, Ill. 407 p.

Tisdale, E. S. 1931. Epidemic of intestinal disorders in Charleston, West Virginia, occurring simultaneously with unprecedented water supply conditions. Amer. Jour. Public Health 21:198-200.

Transeau, E. N. 1951. The Zygnematacea (Freshwater Conjugate Algae), with keys for the identification of genera and species. Ohio State Univ. Press, Columbus, Ohio. 327 p.

Turing, H. D. 1952. River Pollution. E. Arnold and Co., London, England. 93 p.

Turre, G. J. 1955. Algae and other natural sources of tastes and odors in water supplies. Chap. 2 in Taste and Odor Control in Water Purification. W. Va. Pulp and Paper Co., N. Y., Bull.

U. S. Public Health Service. 1956. Central Missouri River water quality investigation for 1955. U. S. Dept. Health, Ed. and Welfare, Public Health Service, Water Supply and Water Pollution Control Section, Region 6, Kansas City, Mo. 50 p. (Mimeographed.)

van den Hock, C., F. Colijn, A. M. Cortel-Breeman, and J. B. W. Wanders. 1972. Algal vegetation types along the shores of inner bays and lagoons of Curacao, and of the lagoon lac (Bonaire), Netherlands Antilles. Verkandelingen der Koninklijke Netherlandse Akademie van Wetenschappen, afd. Natuurkunds-Tweede Reeks, Deel 61. No. 2: 1-72.

Van Horn, W. M. 1950. The biological indices of stream quality. Proc. 5th Indus. Waste Conf. Purdue Univ., 1949. Purdue Univ. Eng. Bull. 34:215-222.

Ward, H. B. and G. C. Whipple. 1945. Fresh-water biology. J. Wiley and Sons, New York. 1110 p.

Water Pollution Control Unit. 1954. Report on water pollution study of Mahoning River Basin, San. Engr. Div., Ohio Dept. Health. 91 p.

Weber, C. I. 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. National Environmental Research Center, Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, Ohio. Program Element 1BA027. 187 p.

Weber, C. I. and D. R. Moore. 1967. Phytoplankton, seston, and dissolved organic carbon in the Little Miami River at Cincinnati, Ohio. Limnol. Oceanog. 12:311-318.

Welch, P. S. 1952. Limnology. Rev. ed. McGraw-Hill, New York.

West, G. S. and F. E. Fritsch. 1927. A treatise on the British freshwater algae. New and rev. ed. University Press, Cambridge, England. 534 p.

Whipple, G. C., G. M. Fair, and M. C. Whipple. 1948. The microscopy of drinking water. Ed. 4. J. Wiley and Sons, New York. 586 p.

Whitford, L. A. and Y. C. Kim. 1971. Algae from Alpine areas in Rocky Mountain National Park. Amer. Midl. Naturalist 85:425-430.

Wien, J. D. 1958. The study of the algae of irrigation waters. Arizona State College, Tempe, Arizona. 37 p. (Mimeographed.)

Wien, J. D. 1959. A study of the algae of irrigation waters. Second Ann. Progress Rept. Arizona State Univ., Tempe, Arizona. 26 p.

Williams, L. G. 1955. Can sewage be converted into human food? Furman Univ. Faculty Stud. 2 (No. 2):16-24.

Williams, L. G. 1960. Uptake of cesium-137 by cells and detritus of *Euglena* and *Chlorella*. Limnol. Oceanog. 5:301-311.

Williams, L. G. 1963. Plankton population dynamics. U. S. Pub. Health Serv. Publ. No. 663 — Suppl. 2. 90 p.

Williams, L. G. 1964. Possible relationships between plankton-diatom species numbers and water-quality estimates. Ecology 45:809-823.

Williams, L. G. and Q. Pickering. 1961. Direct and food-chain uptake of cesium-137 and strontium-85 in bluegill fingerlings. Ecology 42:205-206.

Williams, L. G. and C. Scott. 1962. Principle diatoms of major waterways of the United States. Limnol. Oceanog. 7:365-379.

Williams, L. G. and H. D. Swanson. 1958. Concentration of cesium-137 by algae. Science 127:187-188.

Wisnieuski, T. F. 1948. The chemistry and biology of milk waste disposal. Jour. Milk and Food Tech. 11:293-300.

Wright, S. 1955. Limnological Survey of Western Lake Erie. U. S. Dept. Interior, Fish and Wildlife Serv. Special Scientific Rept.: Fisheries No. 139. 341 p.

Young, G. 1973. Superior-Michigan-Huron-Erie-Ontario. Is it too late? National Geographic 144 (2):147-185.

Youngquist, C. V. 1953. Lake Erie Pollution Survey. Final Report. State of Ohio, Dept. Natural Resources, Div. of Water. 201 p.

Glossary

Actinomycetes. A group of branching filamentous bacteria, reproducing by terminal spores. They are common in the soil. Selected strains are used for production of certain antibiotics.

Aeration. The mixing of water or other liquid with air, including the absorption of air through the surface of the liquid.

Aerobic. A condition involving the presence of free (elementary) oxygen in a medium such as water or sewage.

Algae (singular, alga). Comparatively simple plants containing photosynthetic pigments. A majority are aquatic and many are microscopic in size.

Algicide (or algaecide). A chemical highly toxic to algae and satisfactory for application to water.

Alpha-mesosaprobic zone. Area of active decomposition, partly aerobic, partly anaerobic, in a stream heavily polluted with organic wastes.

Alternate branching. Only one branch per node or at any one height on a filament or strand.

Anaerobic. A condition involving the absence of free (elementary) oxygen in a medium such as water or sewage.

Anterior. The front or forward end of an organism that is capable of movement.

Aquatic. Living in water.

Arcuate. Moderately curved, like a bow.

Areal standard unit. An area of 400 sq microns, used as a unit in designating the amount of plankton in water.

Armored flagellates. Flagellates having a cell wall composed of distinct, tightly arranged segments or plates. The wall is generally thick, rough, and brown.

Aromatic. A fragrant, spicy, or pungent odor.

Attenuation. A continuous decrease in width of a filament, often to a point or thin hair.

Backwash. The cleaning of a rapid sand or mechanical filter by reversing the flow of water upward through it.

Bacteria (singular, bacterium). Simple one-celled but often colonial microorganisms, typically free of chlorophyll, and rigid in form. Their common method of reproduction is by cell division. With few exceptions they live on organic materials.

Benthic. Referring to aquatic organisms growing in close association with the substrate.

Benthos (or benthon). Aquatic microorganisms capable of growth in close association with the substrate.

Bioassay. By using algae or other living organisms or cells, a determination of the biological effect of a substance, factor, or condition.

Biological. Associated with or caused by living organisms.

Biology. The field of study dealing with living organisms. It may be divided into the study of plants (botany) and of animals (zoology).

Blanket algae. A mass of filamentous algae floating as a visible mat at the surface of the water.

Bloom. A concentrated growth or aggregation of plankton, sufficiently dense as to be readily visible.

Blue-green algae. The group Myxophyceae, characterized by simplicity of structure and reproduction, with cells in a slimy matrix and containing no starch, nucleus, or plastids and with a blue pigment present in addition to the green chlorophyll.

Bound carbonates. The nearly insoluble monocarbonates present in water, where a balance is maintained between the amounts of bound, half-bound, and unbound carbonates.

Calibration. Determination of the dimensions of a line, area, or mass present in an instrument such as a microscope. It is accomplished by measurement with a known scale.

Calyptra. A cap or lid on some terminal cells in certain filamentous blue-green algae.

Capitate. Presence of a round cell at the end of a filament; a cell with a rounded enlarged end.

Cell. The organized ultimate unit of structure and growth of a plant or animal. It is composed of a protoplast which, in plants, is generally surrounded by a cell wall.

Cell face. The particular surface of a cell which confronts a person who is observing it under a microscope.

Cell sap. The watery fluid of a cell which may separate from the gelatinous protoplasm to form one or more vacuoles.

Cell wall. The rigid to semirigid, inert, permeable layer of cellulose, silica, or other material which surrounds, and is in contact with, the protoplast of plant cells. It is to be distinguished from the flexible, selectively permeable surface membrane (ectoplast) of the protoplast, and the capsule, sheath, or lorica which may be outside of the cell wall.

Centric. Refers to diatoms which are circular in form in valve view and have radial striae.

Chlorophyll. Green photosynthetic pigment, present in plant cells including the algae.

Chromatophore. A color-carrying body within a cell protoplast.

Clean water zone. That area of water, in a polluted stream, in which self-purification has been completed.

Coagulant aid. A substance which, when added with the coagulant to water, improves the formation of floc.

Coagulation. The agglomeration of suspended or colloidal matter in a liquid such as water, commonly induced by addition to the water of a floc-forming chemical.

Coccoid. Round or subspherical cells.

Colloidal. A condition involving particles dispersed in a medium such as water which do not go into solution or settle out.

Colony. An isolated group of cells which have developed together from a single original parent plant or reproductive cell. Each cell is theoretically capable of life activities independent of the others.

Constricted. The surface wall of a filament curved inward to meet the cross walls, thus leaving grooves on the surface of the filament.

Cooling tower. An enclosure for holding water while its temperature is decreasing. The cooling tower is part of a system which involves absorption of heat by the water from some heat generating apparatus or machinery.

Costae (singular, costa). Thick, rib-like striae in diatom walls.

Cross walls. Transverse walls in a filament, dividing it into units or cells.

Crustacea. Aquatic animals with a rigid outer covering, jointed appendages, and gills. Included are the water fleas such as Daphnia and the copepoda such as Cyclops.

Cubic standard unit. A volume equal to 8,000 cu microns and used as a unit in designating the amount of plankton in water.

Culture. A growth of microorganisms in an artificial medium containing the necessary nutrients.

Desmids. Organisms belonging to the subgroup Desmidiaceae of the green algae and characterized by cells of distinctive shapes one half of which corresponds in shape, size, and contents to the other half. In many desmids the two semicells are connected by a short narrow tube (isthmus).

Diatoms. Organisms belonging to the group Bacillariophyceae and characterized by the presence of silica in the cell walls, which are sculptured with striae and other markings, and by the presence of a brown pigment associated with the chlorophyll.

Dinoflagellate. Motile cells having a transverse groove containing two flagella.

Dissolved oxygen (DO). The amount of elementary oxygen present in water in a dissolved state. It is commonly reported in parts per million (by weight), or milligrams per liter, of oxygen in the water.

Distribution system. Pipes or other conduits through which a water supply is distributed to consumers.

Ecology. Interrelationships between organisms such as algae and their environment.

Elliptical. Narrowly oval in form, the greatest width being across the middle rather than nearer one end.

Enrichment. The addition to water of substances which increase the amounts of nutrients used by aquatic organisms in their growth.

Epitheca. The slightly larger half of the two pieces of the diatom wall. It fits as a flanged cover over the smaller but otherwise corresponding hypotheca.

Eutrophication. The process of enrichment with nutrients in a lake, leading to increased production of aquatic organisms.

Eye piece (or ocular). The short cylindrical frame holding a lens or combination of lenses, and fitting into the top of the microscope tube.

Eye Spot. A light-sensitive, red-to-orange body within the protoplast of a flagellate.

False branching (or pseudobranching). A lateral outgrowth initiated by a cross breakage of a filament, followed by the protrusion through the sheath of one or both of the broken ends of the filament.

False raphe (or pseudoraphe). A longitudinal clear space on the valve face of a diatom, and bounded on both sides by lines of striae.

Filament. A linear series of cells, forming a thread, and held together by their cell walls or sheath.

Filter. A bed of sand or related ingredients through which water is passed to reduce the amount of solid and colloidal material in the water.

Filter clogging. The settling of algae, silt, and other substances from the water into the pores and on the surface of a sand or other granular filter bed, thus reducing the rate of flow of the water through the filter.

Filter run. The time between two successive washing operations of a rapid sand filter.

Filter skin (or Schmutzdecke). The scum or gelatinous layer over the top of a slow sand filter and containing various types of aquatic microorganisms.

Filtration. The process used in water treatment plants of passing water through a granular medium such as sand for the removal or reduction in amount of suspended or colloidal matter.

Flagellum. A microscopic whip-like extension present on many of the motile algae and protozoa.

Flavor. An inclusive term for odor plus the tongue sensations of taste, texture, and temperature of a substance.

Flexible. A solid or semisolid body capable of readily changing its shape when subjected to variations in external factors.

Frustule. The cell wall of a diatom.

Fungus (plural, fungi). Simple plants without chlorophyll; in a broad sense they include the bacteria, molds, yeasts, and mushrooms. The simpler forms are one-celled; the higher forms are branching filaments.

Furrow. A groove or trench on the side of the cell of certain flagellates.

Fusiform. A shape in which the broadest portion is in the middle and tapers to both ends.

Gelatinous matrix. Semisolid material surrounding the cell wall; has a characteristic shape or color in the case of some algae.

Genus. A group (in the classification system for plants and animals) into which are placed species that resemble one another more than they do other species.

Girdle view. The side, rather than the front or top, view of a diatom. It reveals the junction (girdle) of the epitheca and hypotheca.

Green algae. Organisms belonging to the class Chlorophyceae and characterized by photosynthetic pigments similar in color to those of the higher green plants. The storage food is starch.

Groundwater. Water (excepting capillary water) located below the surface of the ground, generally limited to that below the water table.

Gullet. An internal sac-like cavity, open to the outside at the anterior end of the cell. It is present in certain flagellates.

Half-bound carbonates. Somewhat soluble bicarbonates present in water where a balance is maintained between the amounts of bound, half-bound, and unbound carbonates.

Hardness. Ability of water to form a curd-like scum when soap is added and to form scale in boilers. It is caused by presence in the water of carbonates, sulfates, and other related substances.

Hay fever. Allergic symptoms involving the upper respiratory tract.

Healthy (portion of) stream. Flowing water in which the aquatic life has not been adversely affected by human activities such as pollution or by other relatively recent changes in the environment.

Heterocyst. A specialized cell in certain filamentous blue-green algae. It is larger, clearer, and thicker-walled than the regular vegetative cells.

Heterotrophic. Referring to organisms that for their metabolism are dependent upon organic matter supplies from sources outside their own bodies.

Hypotheca. The smaller or bottom half of the diatom cell wall, its upturned, flanged edge fitting inside of a corresponding flange of the epitheca.

Impoundment. A reservoir used for collection and storage of a water supply and for its controlled release as required for use.

Impurities in water. Foreign materials present in water, particularly those impairing its usefulness.

Intercalary. Located between other structures rather than at the end.

Katarobic zone. That area of a stream which is free of both organic pollution and its products.

Keel. A ridge present on the valves of some diatoms.

Key. A series of paired, contrasting statements, each pair leading to other pairs of statements and eventually revealing the names of organisms. It is for use in the identification of an alga or other organism.

Lateral. Refers to the side, in contrast to the ends, of the body of an alga or other organism.

Limnology. The ecology of fresh waters.

Lorica. A rigid wall-like covering around a motile cell and separated by a space from the protoplast or cell wall. An opening is present at the anterior end, through which the flagellum extends.

Loss of head. A decrease in water pressure due to friction and commonly expressed in terms of the difference in elevations to which water will rise in open tubes.

Mat. A layer of algae, generally of the filamentous type. The layer may be either floating on the water or covering a substrate.

Membrane. A wide, flat, thin plant body. A partition or covering, such as the flexible, selectively permeable outer surface film of a protoplast.

Metabolic. Referring to the building up (anabolic) and tearing down (katabolic) processes going on within living cells.

Micron. A unit of linear measurement appropriate for describing the dimensions of microscopic organisms. It is equivalent to one one-thousandth of a millimeter and is symbolized by the Greek letter μ.

Microorganism. Any minute organism, either plant or animal, invisible or barely visible to the unaided eye.

Microscopic. An object too small to be clearly visible without the aid of a microscope.

Mold. Any fungus, exclusive of the bacteria and yeasts, which is of concern because of its growth on foods or other products used by man.

Multicellular. An organism with sufficient specialization to require more than one cell for its various growth activities.

Nannoplankton. Unattached aquatic organisms which are so small that very high magnification with the microscope is required to make them clearly visible. The magnification commonly used for them is 430X to 1,200X.

Naviculoid. Having the form of a ship; pointed or wedge-shaped at both ends, and widest at the middle.

Node. A swelling, generally occurring at equal distances along the tube-like strands of certain algae.

Nodule. A lump on the diatom valve located at the center or at the end.

Nonseptate. A tube-like body that is not divided by cross partitions.

Nucleus. An organized, specialized body within the protoplast and containing the chromatin.

Nuisance organisms. Aquatic organisms that are capable of interfering with the use or treatment of water.

Nutrient. A substance, such as a nitrate, absorbed by an organism and essential as a raw material for its growth.

Ocular (or eye piece). The lens or lens combination fitted into a short cylindric holder which, in turn, fits into the top of the microscope tube.

Ocular micrometer. A glass disc, marked with a scale, that fits on the diaphragm of the microscope ocular.

Odor. The property of a substance which permits pleasant or unpleasant sensations of fragrance or smells to be recognized.

Oligosaprobic zone. That area of a stream which contains the mineralized products of self-purification from organic pollution but with none of the organic pollutants remaining.

Opposite branching. With branches attached two per node or at any one height on a filament, tube, or strand.

Organism. A plant or animal. A body that has developed as a result of being alive.

Outer matrix. The sheath or other cell material outside the cell wall.

Oxidation pond. An enclosure for sewage designed to promote the intensive growth of algae. These organisms release oxygen that stimulates transformation of the wastes into inoffensive end products.

Oxygenation. The absorption by water of elemental oxygen which has been released into the water by aquatic plants as a waste product of photosynthesis.

Parietal. Located near or against the margin. A contrasting term, "axial."

Pennate diatom. A diatom which is elongate rather than circular in the valve view. The wall ornamentation is arranged along the sides of the longitudinal axis rather than about a central point.

Peripheral. Located at the margin.

Periphyton. Attached microscopic organisms growing on the bottom or other submerged substrates in a waterway.

Photosynthesis. Process of manufacture by algae and other plants of sugar and other carbohydrates from inorganic raw materials with the aid of light and chlorophyll.

Phytoplankton. Plant microorganisms, such as certain algae, living unattached in the water. Contrasting term: zooplankton.

Pigmented. Having color, particularly that due to the presence of photosynthetic colored material in the cells of algae and other plants.

Pigmented flagellates. Algae that are capable of swimming and are furnished with one or more flagella. They belong to a number of classes, including Euglenophyceae, Xanthophyceae, Dinophyceae, Chlorophyceae (Volvocales only), and Cryptophyceae.

Pipe moss. A mat or mass of growth formed by aquatic organisms that are attached to the inner surface of a water pipe.

Plankton. Unattached aquatic microorganisms growing as bodies dispersed throughout the water.

Plastid. A body in a plant cell that contains photosynthetic pigments.

Pollution. Presence of foreign material in water, particularly that which interferes with its use.

Polysaprobic zone. That area of a grossly polluted stream which contains the complex organic waste matter that is decomposing primarily by anaerobic processes.

Posterior. The hind end of the body of a swimming organism.

Potable. Referring to water which is drinkable as a result of being free of pathogens, toxic materials, tastes, odors, color, and other undesirable physical, chemical, and biological characteristics.

Protoplasm. The gelatinous, colloidal material of plants and animals in which all life activities occur.

Protoplast. The unit of protoplasm comprising one cell.

Protozoa. Unicellular animals, including the ciliates and nonchlorophyllous flagellates.

Pseudonodule. A clear area resembling a swelling (nodule) on a diatom wall.

Pseudoraphe (false raphe). A longitudinal clear space on the valve face of a diatom and bounded on both sides by striae.

Pseudovacuoles. Numerous minute bodies, resembling oil globules, in cells of certain planktonic blue-green algae. Their function and content are not fully determined. They appear as black granules under high magnification.

Punctae. Pores (appearing as dots) arranged in rows (striae) in diatom walls.

Pure culture. A growth in an artificial nutrient medium of a single kind of microorganism and with no other kinds of organisms present.

Pyrenoid. A body, often within a plastid, around which starch granules are aggregated.

Radii (singular, radius). Lines extending from the center of a circle and at right angles to tangents.

Raphe. A line (cleft) or clear space extending lengthwise on the valve surface of a diatom. See true raphe and false raphe.

Rapid sand filter. A bed of sand for water treatment constructed to permit a rapid rate of flow of water through it. The rate is commonly from 2 to 3 gal/min/sq ft of filter surface.

Raw water. Water which is available as a supply for use but which has not yet been treated or purified.

Reaeration. Contact of air with water permitting absorption of oxygen into the water from the air.

Recovery zone. The area of a stream in which active, primarily aerobic, decomposition of pollutants occurs.

Red algae. A class of algae (Rhodophyceae) most members of which are marine. They contain a red pigment in addition to the chlorophyll.

Red tide. A visible red to orange coloration of an area of water caused by the presence of a bloom of certain armored flagellates.

Reservoir. A basin, lake, pond, tank, or impoundment which is used for control, regulation, and storage of water. It may be either natural in origin or created by the building of a dam or retaining wall.

Resting spore. A specialized, thick-walled reproductive cell, capable of dormancy and of germination, without sexual fusion, to form a new plant.

Rhodophyceae. A class of algae popularly called "red algae." The cells contain a red pigment in addition to the chlorophyll. Mostly marine forms.

Rigid. Fixed, nonflexible.

Rotifer. A microscopic aquatic animal with a ciliated crown attached to its head. The cilia give the appearance of moving in a regular procession around the rim of the crown.

Sand filter. A bed of sand through which water is permitted to pass to reduce the amount of silt, plankton, colloidal material, and related substances that were present in the water. It is in common use in water-treatment plants.

Saprophytic. The capability by some plants, including certain bacteria and molds, of utilizing dead organic matter as nutrients.

Schmutzdecke. A German term for filter skin; the gelatinous layer over the top of a slow sand filter and containing various types of aquatic microorganisms.

Sedgewick-Rafter method. A procedure for the quantitative determination of plankton in water, involving the use of a special funnel and a special counting slide.

Sedimentation. A phenomenon used in water and sewage treatment in which the rate of flow of the water is reduced or stopped, permitting the settling out by gravitation of the suspended particles.

Semicell. One of the two half-cells of the desmid, the two halves frequently connected by an isthmus.

Semirigid. Capable of limited change in form.

Septum. A cross wall of a filament. A complete or incomplete internal wall of a diatom.

Sewage. The spent water supply after it has received the various household, industrial, and other wastes of a community.

Sewage treatment. Any artificial process to which sewage is subjected in order to remove or reduce its objectional constituents.

Sheath. A covering, usually of mucilage, of one or more cells or of a colony. It may be hard and wall-like or soft and transparent.

Slow sand filter. A bed of sand for water treatment constructed to permit water to flow through it at a relatively slow rate. The rate is commonly from 3 to 6 million gal/day/acre of filter surface area.

Stabilization. Biological transformation of organic wastes into more durable metabolic end products.

Stabilization pond. An enclosure for sewage designed to promote the intensive growth of algae. These organisms provide oxygen that stimulates transformation of the wastes into inoffensive end products.

Strand. A cylindrical, stem-like plant body that is more than one cell thick.

Striae. Lines of pores (appearing as dots) arranged in a regular pattern in the walls of diatoms.

Subspherical. Almost spherical.

Substrate. The substance or base upon which an organism grows.

Surface water. Water that rests upon the surface of the earth in contrast to groundwater.

Symmetrical diatom. Correspondence in shape, size, and relative position of parts of the two longitudinal or transverse halves of a diatom.

Taste. A type of sensation (such as sweet or bitter) that the tongue recognizes in addition to the texture and temperature of a substance.

Taxonomic. Emphasis on the classification and identification of organisms.

Thallus. The plant body of an alga or fungus, composed of one or more cells.

Threshold odor number. A unit designating the intensity of odor in water as determined by its perception in a series of dilutions with odor-free water.

Tolerance. Relative capability of algae or other organisms to endure or adapt to an unfavorable factor.

Tongue sensation. The feel or texture that the tongue registers when in contact with water containing various solutes. This is in addition to the sensations of taste and temperature.

True branching. An elongated lateral growth initiated by the longitudinal division of a marginal cell or cells in a filament or strand.

True raphe. A slit (appearing as a line) extending almost the length of the valve face of a diatom and interrupted in the middle by a nodular area. The raphe is bounded by a clear area which, in turn, is bounded by striae.

Tube. A thread-like plant body, one cell wide, that is not divided into segments by cross walls.

Unbound carbonates. The soluble carbonic acid present in water where a balance is maintained between the amounts of bound, half-bound, and unbound carbonates.

Unialgal culture. A growth of only one kind of alga in an artificial nutrient medium, but not necessarily free of other types of microorganisms such as bacteria and protozoa.

Unicell. An organism composed of an isolated single cell.

Unicellular. One-celled.

Unsymmetrical diatom. Lack of correspondence in shape, size, and relative position of parts in the two longitudinal or transverse halves of a diatom.

Vacuole. An area within a protoplast which contains a liquid such as cell sap or oil.

Valve view. The top surface, rather than the side, of the epitheca or hypotheca of a diatom.

Water mites. Small, sometimes microscopic aquatic organisms with a more or less round unsegmented body and with four pairs of legs and one pair of palpi (processes attached to the mouth).

Water quality. Those characteristics of a supply of water which are important in determining its purity and usefulness to man.

Water table. The surface of a body of groundwater when its level is not confined by any overlying impermeable layer of rock or soil.

Whipple micrometer. A subdivided square, marked off on a glass disc, that fits into the microscope ocular. At a magnification of 100X, in many microscopes, the square covers approximately 1 sq mm of the microscope field. It is designed for use in plankton counting.

Whorled branching. More than two branches per node or at any one height on a filament or strand.

Yeast. Unicellular fungi which in general commonly reproduce by budding, and ferment one or more carbohydrates with the production of gas.

Zooplankton. Protozoa and other animal microorganisms living unattached in water.